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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD CONFERENCE PROCEEDINGS 500

Integrated Target Acquisition and Fire Control Systems

(Systèmes Intégrés d'Acquisition d'Objectifs et de Conduite de Tir)

Papers presented at the Avionics Panel Symposium held in Ottawa, Canada, 7th—10th October 1991.

NORTH ATLANTIC TREATY ORGANIZATION

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North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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Theme

Within the scope of NATO missions, the characterisation of targets is of primary interest, because it is needed for establishing the tactical situation, optimising target acquisition systems and optimising armaments utilisation. The problem of detection, recognition and identification is becoming more and more difficult because of increased enemy defence ranges, improved camouflage and jamming techniques and reduction in target signatures. Consequently the operational specifications of airborne systems emphasise the necessity to obtain information on threats which have low signatures and are equipped with counter-measure systems. The use of these technologies dictates multispectral analysis of targets. Solutions could be derived by the fusion of data from several sensors

These solutions must take into account the need to reduce crew workload which could be achieved by automation

This symposium will begin with a session pointing out the needs expressed by the users of airborne target acquisition and fire control systems (including aircraft, helicopters, unmanned air vehicles (UAV), missiles, etc.) The performance and limitations of present techniques will then be reviewed and analysed The "multi-sensor techniques" capabilities will then be described for future Air-to-Air Combat and Air-to-Surface attack missions.

The sessions are.

Session I Expression of Needs
Session II Integrated Systems Architectures and Technologies
Session III Integrated Systems Algorithms
Session IV Short-Term Systems and Equipments
Session V Longer Term Systems

Thème

Dans le cadre des missions de l'OTAN, la caractérisation des objectifs est primordiale car elle permet d'établir la situation tactique, d'optimiser les systèmes d'acquisition d'objectifs et les doctrines d'utilisation des armements.

Les problèmes liés à la détection, à la reconnaissance et à l'identification deviennent de plus en plus complexes à cause de l'accroissement des portées des systèmes de défense ennemis, des améliorations constantes dans les domaines du camouflage, des progrès révolutionnaires en matière de furtivité. En conséquence, les spécifications opérationnelles des systèmes aéroportés mettent de plus en plus l'accent sur la nécessité d'obtention du renseignement sur les menaces discrètes et équipées de systèmes de contremesures. La détection et l'identification de telles menaces exigent des analyses multispectrales. Ces solutions conduisent à la fusion d'informations de plusieurs senseurs.

De telles solutions doivent également prendre en compte la réduction de la charge de travail de l'équipage

Ce symposium débutera par une session destinée à faire le point sur les besoins exprimés par les utilisateurs de systèmes d'acquisition d'objectifs et de conduite de tirs aéroportes (sur avions, hélicoptères, UAV, missiles)

Le point des techniques actuelles avec leur limitations sera analysé et les possibilités offertes par les «techniques multicapteurs» seront decrites pour le combat «Air-Air» et pour l'attaque «Air-Surface».

Les sessions seront les suivantes

Session I Expression des Besoins
Session II Architectures et Technologies des Systèmes Intégrés
Session III Algorithmie des Systèmes Intégres
Session IV Applications à Court Terme
Session V Applications à plus Long Terme

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by

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62nd Avionics Panel Symposium
7-11 Oct 91
Theme
Integrated Target Acquisition and Fire Control Systems

1. INTRODUCTION

Mr Chairman, good morning ladies and gentlemen. Bonjour mesdames et messieurs. En tant que Chef de la Doctrine et des Opérations Aériennes, c'est avec grand plaisir que j'ai accepté de me joindre à vous aujourd'hui et d'avoir l'honneur de lancer cette importante conférence. Le sujet traité, soit les technologies entourant les systèmes de détection intégrée et de guidage terminal, constitue un domaine de grande portée qui me tient beaucoup à coeur.

2. BACKGROUND

Before addressing the subject at hand I feel it is necessary to place future weapons platform requirements in the context of today's world. In doing so we must recognize the risk involved in predicting the future and also acknowledge the significant political and military alliance changes that have come about in recent years and are bound to continue for some time.

The requirement for sensor fusion for fire control systems discussed to date has been on a scenario that is to some extent outdated. However the requirement for sensor fusion still exists within the NATO context and is in the interests of peace making worldwide. Now, let me amplify this further.

For more than forty years, the clash of east-west ideology has dominated the world scene. This relationship no longer carries the threat of imminent large scale conflict between NATO and the now nonexistent Warsaw Pact. However, smaller scale conflicts are likely to continue in other areas of the world, as witnessed by the Persian Gulf war, the war in Afghanistan, Cambodia and now Yugoslavia.

Dans le cas où les membres des Nations-Unies seraient appelées à rétablir la paix dans ces régions, je crois fermement en l'importance d'avoir une force de l'OTAN standardisée où les forces militaires nationales peuvent fonctionner efficacement en concert les unes avec les autres. Cette capacité fût la clé de l'impressionnante flexibilité démontrée par les forces en présence et du succès indéniable de l'Opération Tempête du désert.

The increasing importance of the peacemaking role on the international scene will mean that Canada, as an active member of NATO and the United Nations, will be called upon more often.

Peacemaking implies that one is willing to fight to restore peace. This requires a well equipped and coordinated multinational force to engage in this kind of operation. To achieve success, as demonstrated in the Persian Gulf, strategic and tactical sensor fusion must be achieved between participating forces to effectively build an accurate order of battle and to conduct effective battle management. An integral part of the argument for multisensor fusion is that most nations can no longer afford gilt edged solutions to specific problems. In the face of budget constraints most procurements must be low cost and capable of multiple tasks.

3. DISCUSSION

The bringing together and integration of the many sensors that would be present in a multinational force is no easy task. However, the resulting fusion into a coherent package is essential to minimize effort and expense while maximizing the fighting capability of the force. At the strategic level, this means that we in NATO must continue to do the research and development necessary to find more effective ways to fuse our national detection and acquisition systems with all-source intelligence in order to best meet potential challenges and commitments in the future.

Within NATO we have progressed with BICES (the Battlefield Information Collection and Exploitation System) for fusion of battlefield information. A natural extension is the fusion of tactical sensors to better manage our war fighting

assets by improved target acquisition, weapons selection, prioritization and finally fire control systems.

I am pleased to see that sensor fusion will be thoroughly discussed during this Symposium as I believe it represents a potential breakthrough and will influence the way we conduct operations in the future. For example, long range identification remains an unresolved problem, sensor improvement and fusion are essential to a resolution of this challenge. The fusion of various radar, electro-optic, infra-red and other sensors will also help to eliminate periods, such as in bad weather or darkness, when at present normal operations are reduced or at worst, must cease. Conversely, we can see that sensor fusion will also reduce the potential vulnerabilities of single sensor dependency.

To Canada, on the air side, this means integrating the weapon system capabilities of the CF-18 squadrons we have committed as rapid deployment contingency forces with other national and NATO assets like; reconnaissance satellites, AWACS, JSTARS, UAVs, and other radar, optic or IR sensors to name a few. In order to use our weapon systems to maximum advantage, we must fuse our capability in such a manner as to reduce the risk of overkill but ensure that when a weapons system is assigned a target it is positioning and capable of dealing effectively with that target.

Our experience in the Persian Gulf war showed that Canadians were adequately prepared for the air-to-air war but lacked the precision guided munitions necessary to take advantage of the CF-18's fire control capability to deliver some types of smart munitions. Yet we also noted that while we lacked the target designators and control systems necessary to deliver other types of sophisticated weapons, we were able to fuse our resources with other nations to get our weapons on target.

An example of the way of the future was the use of maturing American unmanned air vehicle (UAV) systems in the Persian Gulf. They demonstrated the ability to locate and identify targets without putting human resources at risk. They were also used to deceive enemy air defence systems and when equipped with cameras were widely used to adjust naval gunfire, artillery, check weather conditions at the target and assess battle damage.

Another system that proved valuable, particularly to the CF-18, was the ability to data link information from the USN tactical operations centre direct to the CF fighter cockpit. In the crowded communication environment such as that present in the Persian Gulf, the timely delivery of fused tactical data link information enable us to avoid the long, sometimes confusing, transmissions that would have added a degree of vulnerability to the mission at hand.

4. CLOSING REMARKS

Je pourrais m'attarder plus longuement sur le sujet de fusion des capteurs mais jugeant par la liste des éminents invités en présence, je vais leur confier la tâche d'élaborer davantage sur ce sujet.

However, as a closing note to be considered in your discussions, I remind you that most of our nations are and most likely will continue to be constrained by shrinking defence budgets and increasing weapon systems costs. Therefore, cost-effective solutions must play an important part in your deliberations.

These facts make your task at this Symposium assume an importance that is critical to the success of future NATO and other alliance military operations. I can assure you that we in the CF will be paying close attention to this issue in light of our recent defence review and will be extremely interested in the results of this effort. I hope you have a productive meeting. That completes my presentation. Once again, I wish you every success in your deliberations.

INTRODUCTION

par

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Mesdames et Messieurs,

C'est un honneur pour moi d'être Chairman de ce 62ème Symposium du Panel Avionic de l'AGARD. Lorsque le thème de ce Symposium fut choisi, voici plus de deux ans, je ne pensais pas qu'il deviendrait si rapidement d'une telle actualité lors des événements qui se sont déroulés en début d'année dans le Golfe. Chacun a pleinement ressenti l'importance qu'il y avait à disposer de *techniques sûres* et fortement *automatisées* pour l'Acquisition des Objectifs et les Conduites de Tir Aéroportées. Le theme débattu pendant ces quelques journées prend donc un relief particulier, et ce d'autant plus que dans l'avenir les specifications se feront de plus en plus exigeantes en matière

- de discretion et de furtivite,
- d'accroissement des distances de sécurité, et, par conséquent, des portées d'acquisition,
- de resistance aux contre-mesures,
- de reduction de la charge de travail des équipages,
- de polyvalence des systèmes.

D'où la necessite de faire appel à de multiples capteurs et de traiter leurs informations pour faire échec aux moyens de *camouflage*, de *leurrage* et de *brouillage* de l'ennemi. La multiplicité des capteurs et des fonctions exige une intégration de plus en plus poussee et des moyens de traitement en temps reel de plus en plus performants, compatibles d'encombrements, masses, consommations et coûts raisonnables. Ces aspects seront discutes au cours de ce Symposium, et ce, dans divers cadres d'utilisation.

- Avions de combat et d'attaque au sol,
- Helicoptères,
- UAV,
- Missiles

Je tiens à remercier les conférenciers qui, pour la plupart, ont repondu tres rapidement au "Call for Papers".

Tous mes remerciements egalement au Comité Technique de Programme.

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Je remercie ce comité pour ses actions efficaces dans la recherche, la sélection des exposés, et dans l'organisation des sessions du Symposium. Je remercie également le Lt Col Fred Sautter qui a remplacé récemment le Lt Col Clay comme Executive Officer. Aujourd'hui, lundi 7 octobre la Session I traitera de l'Expression des Besoins, grâce à quatre "Invited Papers" qui seront présentés ce matin. La Session II, relative aux Architectures et aux Technologies des Systèmes Integres, débutera cet après-midi et s'achevera demain 8 octobre en milieu de matinée. Ce même jour, la Session III sera centrée sur les problèmes d'Algorithmie. En fin d'apres-midi et mercredi 9 matin en Session IV, seront présentes des exemples de Systèmes et d'Equipement en cours d'Essais ou de Développement. L'après-midi sera consacrée a des visites techniques. Jeudi 10 octobre matin, la Session V sera consacree à la description de quelques Projets de Systèmes futurs. Nous prévoyons une Table Ronde, egalement jeudi matin en Session VI afin de donner libre cours à une discussion générale. Compte tenu de l'annulation de certains exposes, le Symposium s'achèvera jeudi 10 en fin de matinee.

OPERATIONAL NEEDS FOR AN UNMANNED AIR VEHICLE

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DISCLAIMER

The views expressed in this paper, together with any recommendations, are those of the authors and not those of the Department of National Defence or the Government of Canada.

SUMMARY

In order for sound and timely decisions to be made, commanders and staffs require a continuous source of information about the tactical situation they are facing. Enemy dispositions and and intentions are of particular importance to any commander, and present the greatest challenge to discern. Unmanned Air Vehicle (UAV) technology offers a potential solution to augment a commander's surveillance resources. UAVs offer the land force commander the possibility of conducting wide area surveillance and target acquisition in near real time. UAVs will extend the range of observed fire to the limits of available weapons. Other supporting functions such as communications relay, electronic warfare and chemical recconnaissance wil also benefit from a UAV platform. Maritime forces could employ UAVs from, or in support of small ships to augment manned aircraft. Over-the-Horizon Targeting, Battle Damage Assessment, Electronic Warfare and Anti-Submarine Warfare are some of the functions which could be supported by a maritime UAV. This paper will examine the requirements for UAVs to support both land and maritime operations. The characteristics and concept of employment which make UAVs desirable for military applications will be discussed.

I. INTRODUCTION

1. Surveillance and then targeting form the basic elements of every weapons system. In early conflicts, the ability to see an enemy was essential before you could employ your own weapons. This was not a problem as the range of the weapons was very short. As a result, line of sight restricted early conflicts on both the sea and land.

2. As weapons technology improved, so did the effective range of the weapons. This extended the range requirement for surveillance and targeting. Nations used kites, balloons and later aircraft in an attempt to extend the line of sight. Technological advances such as radar and IR sensors augmented visual surveillance, but the sight line limit was still present. With the exploitation of height to extend sight lines came systems designed to deny the enemy the use of height. Sophisticated air defence systems evolved which made the use of manned platforms risky and in some situations politically unacceptable.

3. Technology has extended our use of height to space. Space based surveillance platforms are the "cadillac" solution to the surveillance and targeting problem. The cost, frequency of coverage and conflicting user demands make this solution impractical for many tactical applications. Small Unmanned Air Vehicles do however offer a significant potential for fulfilling the surveillance and targeting role.

4. This paper will examine the various operational requirements for unmanned air vehicles concentrating on the naval and land roles of these systems.

II. SEA BASED UAV OPERATIONS

OPERATIONAL CONCEPT

5. A Naval Unmanned Air Vehicle system must operate within a country's existing force structure and within the guidelines set out in the country's maritime strategy. A maritime strategy may have several aims:

a. to be aware of all activities in maritime areas for sovereignty, economic management of resources, and the environment;

b. to provide a secure environment within which legal and regulatory enforcement can proceed unhindered and unchallenged;

c. to act against undesirable activities in maritime areas; and

d. to make a contribution to international cooperative security endeavours. This includes collective defence, arms control and peacekeeping.

6. The ability to conduct surveillance and targeting over marine areas of interest is a cornerstone of any maritime strategy. The surveillance requirement exists in both peacetime and wartime operations. Naval units must be capable of conducting surveillance and targeting while providing for their own self-defence in a hostile environment.

7. The war at sea is a three dimensional affair consisting of the sea surface, the air space above it and the waters below. For ships to operate effectively in these warfare areas they require a capability in Electronic Support Measures (ESM), Electronic Counter Measures (ECM), communications relay, Over-The-Horizon Detection, localization, classification and targeting, Battle Damage Assessment and Anti-Submarine Warfare (ASW). Extending the horizon of the ships sensors can improve all of these capabilities by increasing the time available to respond to the threat.

8. Manned aircraft have traditionally carried out surveillance and targeting missions beyond a ships sensor horizon. These aircraft may be either ship or shore based units. Increases in the capability of shipboard defensive systems has made manned aircraft missions increasingly hazardous. The manned aircraft normally used to extend the sensor horizon must operate in a high risk environment during hostilities.

9. Unmanned Air Vehicles offer potential for significantly enhancing a ship's sensor and weapon system capability while reducing the dependence on costly manned aircraft. Maritime UAVs have long been of interest but it is only recently that key UAV technologies have advanced to the point where unmanned systems are realistic for small ships.

10. For small ships, UAVs are seen as a cost-effective means of offretting the lack of or complementing a limited number of on-board aircraft. UAVs may reduce the loss rate of manned aircraft in high risk environments and improve the self-defence capability and mission effectiveness of surface combatants. The conclusion reached by national and NATO studies is that it is possible to operate UAVs from frigate-size and smaller ships and that operational roles exist for such systems.

UAV EMPLOYMENT

Electronic Support Measures (ESM)

11. UAV(ESM) systems would extend the ship's ESM sensor ranges. This allows monitoring of hostile force activity without drawing on shipboard helicopters or maritime patrol aircraft. The ability to cross fix between two UAV's or a UAV and ship provides a better surface picture to the Task Force. It is desirable to deploy a system which would cover both the communications and radar frequency bands. Bearing accuracy of 5 degrees or less is desirable as is an onboard threat library.

Electronic Countermeasures (ECM)

12. ECM in the naval environment exists in two forms, defensive and offensive. The threat of the high speed, low altitude anti-ship missile has become more prevalent. The time available to defeat these weapons has decreased. The UAV(ECM) is seen as a useful adjunct to existing systems by extending a jammer's horizons. This increases the time available to respond to the threat.

13. A ship could deploy a UAV(ECM) in a station relative to the ship for extended periods. With the UAV(ECM) prepositioned on the threat axis, the ship can respond rapidly as soon as the threat radiates. The UAV(ECM) would attempt to confuse the missile through false target generation, or confuse it through various jamming techniques. Chaff dispensing from the UAV(ECM) is an alternative to seduce and confuse targeting radars. Through the UAV(ECM) data link sub-system, cooperative jamming could be achieved between ship's jammers, the UAV(ECM) system and target ship's chaff and decoy systems.

14. In an offensive role, The UAV(ECM) system would have a geometry advantage. The UAV(ECM) can conduct jamming without providing hostile forces with a "Jamming Strobe" bearing line back to own forces. The UAV(ECM) system can also operate closer to enemy forces without risking loss of life. This provides a higher Jammer to Signal Ratio which increases the effectiveness of the jamming.

15. A typical ECM payload could consist of a noise/repeater jammer system and CHAFF. Broadband coverage for the noise/repeater jammer is desirable.

Communications Relay (CR)

16. Good communications are essential to a Task Group. Because of the increased ranges of senors and weapon systems, the ships of a Task Group may operate in dispersed formations over distances approaching and often exceeding 100 NM. Therefore over-the-horizon communications and good data links are mandatory. The current methods used include HF radios and UHF radios using airborne relays such as

helicopters, maritime patrol aircraft and satellites. HF radio is the least desirable because of the potential intercept ranges. UHF radios require some form of airborne relay to provide over the horizon communications. This is rarely possible 24 hours a day nor is it cost-effective.

17. An automatic data link or voice UHF relay provided by an UAV(CR) would insure timely and accurate transfer of information between the C^3 ship and other dispersed units. For example, two towed array ships separated by more than 60 NM from each other may be processing a cross fix on a submerged contact. They could use the UAV(CR) to provide data link to each other and to the Task Group Command ship which may be 100 NM away. The payload should ideally be multichannel and must accommodate modern frequency hopping radios.

Over-the-Horizon Detection, Localization, Classification, Targeting and Battle Damage Assessment (OTHT/BDA)

18. Many surface combatants carry surface-to-surface missiles such as Harpoon and Tomahawk. These missiles require accurate targeting information to be effective. At present, helicopters or maritime patrol aircraft provide the necessary third party targeting. In doing so however, they expose themselves to extreme risk from a targets air defence systems.

19. The ship would employ the UAV(OTHT/BDA) in peacetime or rising tension to classify surface contacts. The aim is to maintain as accurate a surface plot as possible. Once hostilities begin, the UAV (OTHT/BDA) targets these contacts for engagement at the maximum range of the shipboard weapon systems. The range required for a UAV to be effective in surveillance and targeting would have to be further than the range of present weapon systems. This is to enable enough time to identify the target and gain targeting data before the target enters the maximum engagement range.

20. After an engagement, a UAV would close a contact and determine the level of damage. The UAV which conducts the targeting may be the UAV tasked with BDA. The UAV tasked with BDA must provide high resolution imaging data to allow for assessment of structural and system damage. Multi-spectral sensors would enhance BDA. The UAV providing BDA must also provide enough targeting information to enable ships to conduct a second engagement if required. The payload most suited for surveillance, targeting and battle damage assessment is a combination of ESM, Imaging Radar, Forward Looking Infra-red (FLIR) or Low Light Level TV.

Anti-Submarine Warfare (ASW)

21. With the longer detection ranges generated by towed array sonar systems, there is a requirement to provide reactive vehicles to localize and prosecute. The Navy currently uses helicopters and MPAs to carry out these tasks. A limited numbers of these resources are available to the Task Group. Ships could employ the UAV(ASW) to assist by dropping small sonobuoys in various scenarios. Ships could employ UAV's to monitor and relay acoustic information from previously deployed sensors to the Task Group. Although the UAV could not take the place of current air assets, it would relieve them of high risk or tedious tasks.

MISSION PLANNING

22. Ideally, ships will deploy the UAV in a similar manner as manned helicopters. The unit commander can launch the UAV at his discretion to fulfil the combat mission of the ship. The Task Group Commander may also deploy the UAV as a force asset in response to requests from other units.

23. The mission planning process provides detailed flight plans necessary to conduct a UAV mission. In its simplest form this function combines and prioritizes UAV task orders requested by a variety of sources within the ship and Task Group. Ship's staff develop the plans based on the current/expected UAV situation status, as well as standard operating procedures. The UAV Operator enters approved plans into the Command and Control System for use by the proper combat system operators. The Operator uses the mission planning process to modify missions in response to changes in the tactical situation and changes in the UAV status.

24. The UAV Operator would carry out the mission plan by creating a flight plan for the UAV and inserting waypoints into the system. Once airborne the Operator controls the flight path of the UAV by the adjustment of waypoints. The UAV would be capable of operating on the preprogrammed flight plan if loss of the data link with the ship occurs. Transmission of the payload data would be in near real time. A provision could exist to store data onboard the UAV for later retransmission.

Single Operator Workstation Concept

25. To fit the UAV system within the space constraints of a ship, the shipboard control station should be a single operator workstation. This workstation would conduct both mission planning and flight control of the UAV. The variety of tasks that the workstation must perform demands a highly versatile multifunction display

the ship's combat system. Sensor data would be distributed throughout the combat data system to the operators trained to interpret the data. Control of the air vehicle and payload may be in response to predefined instructions in the flight plan, by the UAV Operator or in response to the needs of ship's combat system operators using the UAV data. The recovery phase includes the control and monitoring of air vehicle to the recovery point and supervision of the recovery procedure.

29. Ships would deploy UAVs wherever the fleet conducts operations. The UAV would operate in all weather conditions including extreme cold and heat. Ship deck motion limits would be similar to those of the shipboard helicopter.

30. The integration of UAVs with other aircraft would require the adoption of special airspace requirements for the conduct of safe UAV flight. It is likely that manned aircraft and UAVs would fly simultaneously. The maintenance of safe separation distances between all types of air vehicles is essential. In so far as is practical, the use and control of UAVs would be the same as for manned aircraft. The control of emissions from the UAV would follow as closely as possible the established procedures and governing directives for other aircraft operating in the same task group.

31. Ship's may operate multiple UAVs to provide on station relief or greater coverage in the area of interest. The extent of multiple operations would depend on the intensity of activity, number of aircraft operating in the area of interest, data link capabilities and the extent that an operator can manage multiple UAVs from a single console.

SUPPORTABILITY

32. Where possible, ship's will store UAVS in the ship's helicopter hanger. For ships without hangars, storage of the UAV would require a special container to allow modular installation of the systems. UAVs stored in helicopter hangars must not interfere with the storage of the helicopter in the same hangar.

33. On all ship classes, operation and maintenance of UAVs should use existing ship's crew where possible. There is no intention to cross-train Helairdet technicians to maintain or operate the UAV. UAV operations must be independent of but complementary to helicopter operations to insure availability of the system when the Helairdet is not embarked or unavailable. There may be a requirement to increase the ship's firefighter complement in response to the increased flight deck activity. UAV operators would be trained members of the ships crew. UAV Operators would not require special prerequisite qualifications however, experience in air control such as an ASAC qualification could become a requirement.

34. Units would to deploy UAVs for up to six months at a time. Shipboard personnel would only be responsible for first line maintenance.

35. Operation of the UAV would be at a rate similar to the shipboard helicopter. Therefore there is a requirement to operate the UAV system approximately 100 hours per month for peacetime operations at one sortie per day and a peak wartime requirement up to 18 hours per day for three days.

II. LAND BASED UAV OPERATIONS

OPERATIONAL CONCEPT

36. The concept of operations for UAVs employed by land forces is very different from that developed for naval UAVs. The most important reason for this is that the physical environment differs immensely from that of naval forces because the land environment offers a variety of terrain. This causes tactics to be different in concept and execution; creating different operational requirements. Land forces may find themselves in operational situations that require radically different approaches. The requirements of an internal security operation can be very different than those of general war.

37. Since information is hard to obtain, commanders must strive to improve their knowledge, to reduce their uncertainty about what is really happening on the battlefield. It has been argued that in modern warfare commanders are frequently less certain about their enemy and what is going on than their predecessors were a thousand years ago.

38. All commanders will seek to know as much as possible about the battlefield, to "see over the hill" and reduce their level of uncertainty. They will wish to control their surveillance devices in order to be certain that these resources work on the tasks that they consider important.

39. UAVs offer a very attractive tool for commanders to increase their level of certainty. They allow commanders to "see the battlefield" while being less expensive than an equivalent capability manned aircraft. UAVs offer commanders real time information, often in an easily absorbed video format. Being unmanned they can be used on very high risk missions and a lack of aircrew onboard means that the air vehicle can be smaller, improving its chances of survival.

40. UAVs will not solve all problems nor replace manned aircraft for all roles but they do offer ground commanders a valuable resource at relatively low cost.

THE OPERATIONAL ENVIRONMENT OF LAND UAVs

NATURAL INFLUENCES

Effect of Geography

41. Land based military operations are heavily influenced by the geography in which they occur. The widely varying topography and cultural overlay mean that the type of terrain available for deployment in any square kilometre is effectively random. Neither senior commanders nor computers can accurately foresee the low level topography that the enemy will have available to him. It is not possible to fully foresee the enemy's tactical plan.

Line of Sight

42. The random nature of the ground available to the enemy is further enhanced by the ground's effect on line of sight (LOS). It is possible to understand how a particular piece of ground affects the enemy's deployment without understanding fully the effect of surrounding terrain on our LOS to the enemy and his to us.

Effect of Digging

43. The enemy can hide his personnel and equipment under terrain features as well as behind them. This greatly increases the enemy's ability to conceal his forces.

Effect of Weather

44. The concealment offered by the terrain is further enhanced by the effects of local weather. The ground effects of local terrain means that weather can have unique local variations such as fog and mist following the low ground while leaving high features unobstructed.

Combined Effect

45. The concealment opportunities offered by ground make it very difficult to detect fully the enemy force's deployment and surmise its intentions.

TACTICAL INFLUENCES

46. Geographical factors are not the only ones that make it difficult to understand the enemy's actions and intentions. The following paragraphs illustrate how the nature of modern warfare makes it difficult to understand the enemy's posture.

Effect of Modern Weapons

47. The most obvious tactical influence is the destructiveness of modern weapons. The power of modern weapons means that exposed personnel and unarmored equipment have little chance of survival. This is of great importance as the largest portion of land forces consists of unprotected men, unarmored vehicles and installations and lightly armoured vehicles. Both sides will disperse their forces making them less evident to the opponent.

Command Levels

48. All the above factors mean that it is impossible to command large numbers of soldiers directly. To address this problem, armies use a number of command levels. The traditional structure of sections, platoons, companies etc is not an outdated holdover from the past. Rather, it represents a recognition of the number of subordinates that a land commander can effectively lead in a tactical scenario. These commanders have different information requirements.

Communication

49. Advances in modern communications assist high level commanders in their task. Forces can be dispersed for survival and only concentrated when and to the degree necessary to achieve decisive local superiority over the enemy. These improvements have not led to greater centralization of command due to the fact that as technology makes communications more effective, it makes weapons more lethal. This leads to the need for dispersal and requires that the traditional hierarchial structure be retained to bridge the gap.

Effect of Airpower

50. The use of aircraft offers a means of detecting widely dispersed land forces. Planes can cover large areas in a short time and can look down onto the ground, thus obviating the effect of LOS. However, a number of factors prevent aircraft giving commanders a complete view of the battlefield. Land targets are small and are not immediately evident to the human eye or other airborne sensors. Secondly, the effectiveness of tactical air reconnaissance is reduced by ground based air defences. These systems can be highly effective and deployed under local cover, thus making them very hard for pilots to detect. It is easier for the ground based air defence systems to detect aircraft that are silhouetted against the sky than it is for the aircraft to detect dispersed, camouflaged ground systems. The final problem is the fact that modern aircraft cost a great deal of money. It is unlikely that large numbers of aircraft will be available for air reconnaissance, especially when it is believed that the enemy has a capable air defence systems. Commanders will not wish to risk scarce resources to carry out reconnaissance of ground targets with the natural concealment.

Summary

51. Land warfare involves a large number of small elements, dispersed throughout the available terrain, seeking to remain unobserved and working as part of a coordinated team with commanders at a necessarily low level. This makes it very difficult for commanders to be able to see the battlefield. They must devote a great deal of thought and effort to obtaining often the most elementary information about the enemy's forces, deployment and intentions.

UAV EMPLOYMENT

52. The levels of command within an army have corresponding areas of influence and

interest which generally define the type of UAV support required. Commanders become less directly involved with immediate operations as the level of command increases. The doctrinal time and space considerations for brigades, divisions, and corps are given in Table 1.

53. As a rule, a commander will actively seek information and engage the enemy in his area of influence. Information concerning his area of interest is provided by his superior. The interlocking areas of influence and interest impose unique requirements on UAV systems operated at each level.

LEVEL OF COMMAND	AREA OF INTEREST		AREA OF INFLUENCE	
	TIME (H)	DISTANCE (KM)	TIME (H)	DISTANCE (KM)
CORPS	0-96	300	0-72	150
DIVISION	0-72	150	0-24	70
BRIGADE	0-24	70	0-12	15

Table 1
Typical Areas of Interest and Influence

Brigade Level

54. At this level the prime UAV role is surveillance and target acquisition to provide early warning of enemy activity. Although a brigade has limited indirect fire support, there will be some requirement to engage targets beyond the line of sight of its forward sub-units. The requirements at this level include:

a. A high daily sortie rate to support continuous operations;

b. High quality imagery and rapid imagery interpretation to provide timely information;

c. Small UAV infrastructure in order to impose the minimum burden on the supported brigade; and

d. Ground based components must have similar mobility and survivability to that of the brigade's other units.

Division Level

55. The division has several functions which can be enhanced through the use of UAVs. Target acquisition and fire direction by UAVs will allow a division commander to attack enemy formations before they are engaged by his subordinate brigades. Other possible tasks include providing an elevated electronic warfare platform, conducting chemical warfare reconnaissance and collecting target area meteorological data. These varied tasks raise the issue of a multi-role UAV, some of the requirements for which are:

a. Well defined and practised command and control procedures to keep UAVs employed on most important tasks;

b. Modular payloads to cater to various tasks;

c. Well designed Ground Control Station (GCS) to reduce operator workload and to enable use of different payloads;

d. UAV systems capable of integration with other information gathering means to ensure effective and efficient employment; and

e. Ability to conduct target engagements with indirect fire to maximize the effect of long range weapons.

Corps Level

56. At this level information gathered by UAVs can be less time critical than at lower levels. Target acquisition will still be carried out, but the engagement of all targets found might be beyond the capability of the corps' fire support resources. The collection of both imagery and electronic information will be important tasks to support corps level planning of future operations. Some requirements which arise from the corps' role and its time and space considerations are:

a. Range, endurance and speed required to operate in the enemy's rear areas will be much greater than that required by divisions and brigades;

b. A more sophisticated air vehicle will probably be required for corps level use. Supporting a more sophisticated UAV will increase the infrastructure cost. The benefit of employing a more sophisticated system at this level will justify this cost; and

c. The ability of a corps level system to provide vast amounts of raw information will require increased exploitation resources in order to quickly extract the required information.

IV. DIFFICULTIES IN USING UAVs

57. UAVs do not solve all problems. The problems that can be encountered and an idea of what must be done to address them will be discussed in the following paragraphs.

Resource Scarcity

58. Given that land forces are scattered throughout large areas of terrain, armies will not be able to purchase enough UAVs and support personnel and equipment to give them full knowledge of their opponent's deployment. The smaller naval Task Group will not require the same number of UAVs to accomplish it missions. The UAVs that are purchased must be used to maximum effect in support of the commander's requirements.

59. Armies will want to have a suite of UAVs that are matched to the requirements of the various command levels. Navies will prefer a common UAV with multi-mission payloads. Decentralised use, probably by the allocation of a number of sorties, to those agencies that the commander feels have a bona fide requirement for UAV sorties would allow the control necessary. This decentralisation would be supported by the commander's retention of a reserve of sorties; these would be used for urgent priority tasks and to give the commander some flexibility giving him a reserve of uncommitted resources that he can use to cater to the unexpected.

60. This system of sortie allocation requires that a good chain of command for tasking the UAV operators exists. Good command and control procedures must be in place to ensure that UAV taskings are handled consistently, effectively and quickly, while ensuring that information from one tasking is available to all users as required.

Management of Information Flow

61. This dissemination of information should save taskings as some users can get the information they require from previously flown sorties. In the Army environment, ensuring that the proper information gets to the people who need it in a timely fashion is no small accomplishment. One UAV mission could generate several hours of video tape. This must be analysed and disseminated before the information becomes stale. Further, the information system must ensure that users are not swamped with unnecessary information. The use of data fusion and wide area computer networks seem like obvious technologies for resolving these problems. They cannot be the entire solution. A clear institutional understanding of UAV operations is necessary so that the ongoing information needs of all agencies and the real significance of information acquired is known. Everyone must know which piece of knowledge contributes the most to the commander's plan of operations, the discovery of a fuel storage site or 100 tanks found in reserve six hours behind the enemy's apparent main axis. Resources are limited and it will not be possible to shoot at every target, therefore the important ones must be engaged first.

62. The Naval UAV system will be linked directly into the Combat system of the ship. The ship's Combat System will conduct the required data fusion and distribution. Individual operators and Warfare Commanders can access the data they require from the tactical data base.

63. Purchasing UAVs without implementing the necessary change in procedures and doctrine will not obtain the full results possible. An army that does this may be reduced to doing the "same old things" in a different way rather than making significant improvements in reducing its commanders' degree of uncertainty. In fact, such an introduction of UAVs may actually increase commanders' uncertainty by inundating them with clear, real time information that is irrelevant.

Control of UAV Missions

64. Closely related to the above mentioned points are the problems that can arise when armies have to decide exactly what their UAVs are to do on each mission. This problem is particularly severe for multi-role UAVs; which is more important, surveillance or using the UAV with an electronic jamming pod to disrupt the enemy's rear area communications? Even with a single role surveillance UAV the decisions are not necessarily obvious. Is it better to do a wide area surveillance mission to obtain new information or use the UAV as an airborne observation post to direct fire onto targets that have already been identified? During surveillance missions when should UAVs stop and attack targets by directing artillery fire?

65. Clearly, the UAVs must be used to support the commander's aim. This simple statement is not always easy to apply to hard, real life choices. Therefore, UAV doctrine and staff and command training must educate officers about these problems in order to reduce errors in the heat and confusion of battle.

V. A TYPICAL UAV SYSTEM

66. The main elements of any UAV system are:

a. Command and Control element;

b. Ground Control Stations;

c. Support Element; and

d. UAVs and Payloads.

Command and Control

67. Effective command and control is vital if the full potential of UAVs is to be realised. The following list illustrates the coordination required to conduct effective UAV operations:

a. Provision of Advice on UAV Employment. UAV limitations must be made known early to ensure optimum employment of a scarce resource;

b. Coordination With Other Surveillance Systems. UAVs are one element of complementary systems. They must take full advantage of cuing information provided by other systems;

c. Airspace Coordination. The integration of UAVs with other aircraft would require the adoption of special airspace requirements for the conduct of safe UAV flight. It is likely that manned aircraft and UAVs would fly simultaneously. The maintenance of safe separation distances between all types of air vehicles is essential. In so far as is practical, the use and control of UAVs would be the same as for manned aircraft. The control of emissions from the UAV would follow as closely as possible the established procedures and governing directives for other aircraft operating in the same task group;

d. Fire Support Coordination. In both the sea and land environments, UAVs require well understood and rehearsed fire control procedures to be an effective fire direction tool. Fire units and ammunition must be made available to engage targets located by a UAV;

e. UAV Deployment. Land UAV elements will have unique siting requirements. Commanders and staffs must understand these so that they can make balanced judgements on terrain control; and

f. Administration. Land UAV elements spread throughout a formation's area require a central agency to control administration to ensure continuous support to UAV operations.

Ground Control Stations

68. The GCS performs detailed planning and minute to minute control of UAV missions. A major factor in GCS performance will be operator fatigue. Continuous operations will require multiple crews to keep a GCS running effectively. A multi role system could compound the manning problem by requiring many unique skills in which a GCS crew will have to remain proficient. A ground based UAV will be physically separated from both its command and control element and from the users of UAV provided information. A crew of two and perhaps three personnel will be required in this case to both control the UAV and conduct the assigned mission. Sea based systems do not suffer this problem as specialist operators are present in the ship to support analysis of UAV data. The obvious requirement in general terms is to automate the GCS to such a degree that a human operator can devote the bulk of his time to analysing information and making decisions while only being required to master a few skills in order to operate in the GCS environment.

Support Element

69. The Support Element is primarily concerned with keeping the UAV and payload inventories serviceable. High usage rates and attendant maintenance requirements are directly at odds with the need to reduce infrastructure. Highly reliable and easily maintained UAVs are required.

UAVs and Payloads

70. UAVs are essential to a UAV system. However, the real value of UAVs is not in a great airframe or sensor but rather in how the operators employ their UAV to support a commander's plan. UAVs and their payloads must be robust to survive field handling. They must have performance and survivability characteristics sufficient to face the expected threat. However, neither the airframe nor the sensor can become so precious that their loss would be unacceptable. While not throw-away items, UAVs and their payloads are built to go into dangerous places to protect manned aircraft. Losses to a units UAV inventory must be seen as inevitable and UAV design must keep this in mind.

VI. SUMMARY - SEA VERSES LAND BASED UAV OPERATIONS

71. Having looked at the nature of sea and land warfare, operational concepts, methods of employing UAVs and the problems associated with such employments, a number of differences become clearer. These are summarized in Table 2 below.

73. No single system will meet both the land and sea requirements. The overall benefit of UAV's is however well

recognized in both communities. Future Orders of Battle will undoubtably find UAV's figuring prominently among land and sea commanders "Tool Boxes".

	SEA	LAND
a.	No or limited terrain features (coastlines);	Varied terrain features;
b.	Centralized command structure involving a small number of individual units;	Decentralized hierarchial command structure involving many small groups;
c.	small number of end users of UAV data;	large number of end users each with differing levels of requirements;
d.	limited number of communication and C^3 nets;	extensive communications and C^3 nets;
e.	Large platforms result in fewer restrictions on UAV system space and weight;	Smaller platform will restrict UAV system space and weight;
f.	Vertical takeoff and landing is essential;	Vertical takeoff and landing desirable;
g.	Single UAV airframe with multi-mission payloads;	

MULTISENSOR AIRBORNE TARGET ACQUISITION SYSTEMS AND THEIR INTEGRATION

by

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1. THE TASK

For the air to ground attack scenario, the task of electro optic sensors is to optimise the process of target acquisition and the subsequent delivery of a weapon to that target.

The increasing range of enemy defence continues to demand greater detection, recognition and identification ranges. Targets frequently have low signatures and the atmosphere may further reduce target contrast. Developments in camouflage and counter measures increase the difficulty of carrying out an already demanding task from a low flying high performance airborne platform under all weather conditions and during daylight or at night. One solution has been to equip the attacking aircraft with imaging sensors which aid the search task by presenting to the crew a magnified image of the scene on a television style monitor in the cockpit. Initially such sensors were based on visible wavelength television and were therefore daylight operation only. These have now been extended to the infra-red region giving a twenty four hour and all weather capability. Enemy forces have responded to the use of such sensors by developing visible wavelength camouflage and later by developing IR counter measures, while at the same time increasing the effectiveness of their defences. Thus the demands on the sensor for higher spatial resolution and greater sensitivity have increased simultaneously from a reduction in target characteristics and a need for increased stand-off range capability.

There has also been a demand for more accurate weapon delivery and this has resulted in the development of smart weapons. This provided increased requirements for the acquisition equipment which must now also be capable of handing over a target to a weapon or of designating it with a laser beam up to impact.

A great deal of work has been carried out over the past twenty years in the development of equipment to provide target acquisition and accurate laser designation. GEC Ferranti has been involved in the development of such equipment over this period of time and has been responsible for the design and fabrication of equipment which provided very accurate designation of small mobile targets from an airborne platform. This has been reported at a previous Agard Conference (Reference 1). It is essential to integrate these systems into the avionics and to optimise the man machine interface in order to achieve the full potential increase in performance. GEC Ferranti has also carried out work to investigate the crew workload and look at ways in which this may be minimised (Reference 2). Current capability is therefore the result of many years of careful development and advancement.

2 INHERENT LIMITATIONS

The performance of any sensor system is constrained by the inherent physical properties of the system. The following discussion is confined to sensors operating essentially as imaging devices in the visible and infra-red regions of the electromagnetic spectrum.

The angular resolution ideally achieved with an imaging sensor system is limited by optical diffraction effects and in its simplest approximation the resolution can be taken to be proportional to the ratio of the wavelength of the radiation to the aperture of the receiver. In order to achieve a compact system, the wavelength chosen must be small. Use of wavelengths in the visible and infra-red region result in both high resolution and small aperture. The latter characteristic is particularly important when the constraints imposed by the airborne platform are taken into account.

The other major factor which influences the choice of wavelength is the overall system sensitivity. This is determined by the energy radiated from the target, the atmospheric attentuation in the path between the target and the sensor and the performance of the sensor/display/operator combination. Sensors operating in the visible and IR wavebands are normally passive devices which rely on natural illumination or the natural radiation from the scene. Passive sensors are preferred for military applications since covert operation is normally an essential requirement to avoid detection and thereby reduce the probability of counter measures being deployed. There are a limited number of transmission "windows" in the atmosphere, the three most useful being visible, 3 to 5 microns and 8 to 14 microns. These are shown in Figure 1. There are a limited number of sensors currently available to exploit these windows. Of these the visible region and 8 to 14 micron imagers have to date the better performance for scene imaging. However recent developments in 3 to 5 micron imaging may change this in the near future.

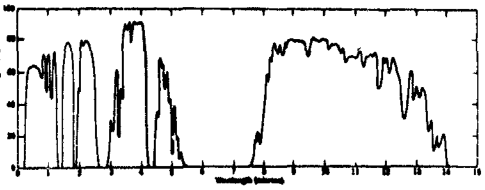

FIGURE 1 : ATMOSPHERIC ATTENUATION

Television sensors have been developed over the last 50 years and have reached a high state of maturity and performance. They operate over the visible region and into the near IR in some cases, and can cope with a wide dynamic range of scene illumination levels. Options exist for using restricted regions of the waveband in order to enhance the performance in haze and under low levels of scene illumination. The properties of natural and man made materials also suggest that a bias towards the red end of the visible spectrum will aid the distinction between a camouflaged target and naturally occurring vegetation. The reflectance of a variety of natural ground cover is shown in Figure 2. Imagers operating in the 8 to 14 micron region have been under development for a much shorter period and have only recently reached a form of maturity. The performance of both types of sensor is well understood and performance models are used extensively for predicting operational performance. Atmospheric effects are also understood and may be accurately modelled using, for example, Lowtran.

3. PERFORMANCE

It is necessary to establish some qualitative measure of performance in order to justify the choice of sensors for a multisensor payload. In a full TV/IR comparison the recommended approach is to make laboratory measurements on the performance of each under well controlled conditions and compare the data for what are considered similar inputs to each

system. This is followed by a controlled flight test programme against bar targets and actual targets to confirm the predictions of the model. Finally an extensive flight trial should be carried out to investigate those conditions which favour one system. This would require testing against a total set of all conditions and in a worldwide context is clearly impractical. Thus predictions based on a subset of all conditions must be made.

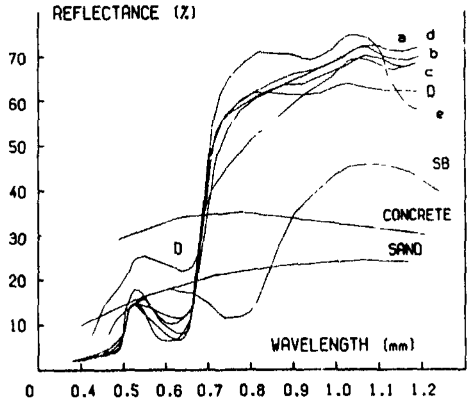

FIGURE 2 : VEGETATION REFLECTANCE VALUES

One may select recognition range as a sensor performance parameter and calculate this value for the two sensors under a wide range of conditions. Performance models exists which enable this calculation to be made with good accuracy and allow valid comparisons to be made. Each condition must be identified by the atmospheric conditions, target parameters, background and time of day. These parameters can vary widely during the year for the majority of locations on the earth's surface. The atmospheric attentuation is known to be dependent on the moisture content of the atmosphere but it is necessary to know the characteristics of the atmospheric moisture before computing the attenuation. Certain aerosols can have a severe impact on TI performance while hardly affecting TV performance.

It is also necessary to define the characteristics of the target adequately and to take account of the correlation between these characteristics and those of the atmosphere. There is obviously a relationship with the time of day and the time of year.

As an example of the range of predicted performance that can be expected to occur in reality, two locations have been selected for a comparative performance assessment. Both are in the Gulf Region. One location is a typically hot and dry semi desert scenario and the second is a hot and humid coastal scenario. The target was defined to consist of a concrete block of five metre edge against semi desert for the first location and against coastal vegetation for the second location. Data was collected over a period of time on an hourly basis. Performance was calculated on an hourly basis and then analysed. This was felt to be more realistic than averaging the data and calculating the performance based on the average conditions. The atmospheric attenuation was computed using the Lowtran atmospheric model and the target characteristics and recognition range computed using in-house models.

The results are shown in Figure 3 for the hot dry location and Figure 4 for the hot humid location. These results should be viewed as a sample of performance over several days at a particular time. They show that at the hot dry location the TV sensor was slightly better during the morning and that at the hot humid location the TV sensor was better during the daylight period. Obviously the TV performance goes to zero between dusk and dawn.

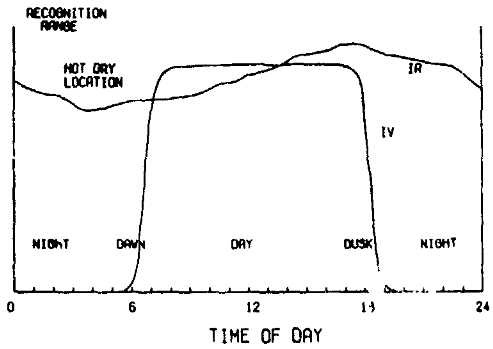

FIGURE 3 : PERFORMANCE HOT DRY LOCATION

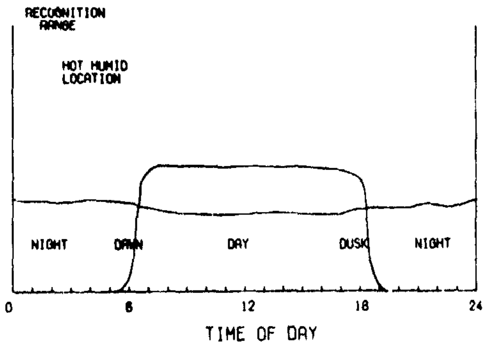

FIGURE 4 : PERFORMANCE HOT HUMID LOCATION

One may conclude that the extra performance achieved from the two sensor system is worth the extra cost of providing the second imaging sensor. The TI imager would be the obvious choice as the prime imager but there are occasions when the TV shall provide enhanced recognition range. The ability to switch between sensors when in the target area can obviously bring a considerable advantage to the multisensor equipped aircraft.

It is also pertinent to consider if the information from both sensors may be combined or fused in a manner which will provide the operator with a single image containing the most relevant features from both channels. A variety of schemes exist to carry out such combining. This has been investigated in our laboratories and a variety of simple super position schemes tried. The results are described below.

4. HARDWARE DESCRIPTION

The multisensor equipment has been configured as a Pod for simple carriage on the underside of an aircraft. A photograph of the Pod is shown in Figure 5 and the major parameters are shown in Figure 6. There are five major subsystems, Thermal Imager, Television, Laser Rangefinder and Designator, Tracker and Sightline Control.

The major elements of the front end of the Pod are shown in Figure 7. Combining optics collect and direct the three sightlines onto a two axis stabilised mirror located at the extreme front end of the Pod. The combination optic consists of the main objective group, the folding mirror and stabilised mirror and the external window. The laser path is combined with the TI path by means of a beamsplitter which reflects the laser and transmits the IR. The TV is injected into the combined TI/Laser optical path. Extensive use is made of multispectral optical materials to permit efficient optical transmission at the appropriate wavelengths. The entire front section can be rolled about the Pod longitudinal axis and the ball may be driven in pitch. The combined action of these two independent servos enables the sightline to be steered

FIGURE 5 : PHOTOGRAPH OF TIALD POD INSTALLED ON A TORNADO AIRCRAFT

FIGURE 7 : TIALD POD FRONT END

through a large field of regard. A two axis gyro stabilised platform provides precision stabilisation of the sightline against vibration inputs.

POD PHYSICAL PARAMETERS

CONFIGURATION	DIAMETER	- 305mm (12")
	LENGTH	- 2900mm (114")
	WEIGHT	- 210kg (462lbs)
INTERFACE	MECHANICAL	- 14" OR 30" FIXING CENTRES
		- MACE AND STANDARD ERU
	ELECTRICAL	- MIL-STD-1553B DATA BUS
		- 625 Line 50HZ CCIR Video
		- 200V 400Hz 3 Ø 2kw max
		- 28V dc
FIELDS OF VIEW	TELESCOPE	- IR 2.4° × 3.6°, 6 7° × 10°
		- TV 2.4° × 3 6°
FIELDS OF REGARD	BALL	- + 30° - 155°
	ROLL	CONTINUOUS ROTATION

FIGURE 6 : TIALD POD MAJOR PARAMETERS

An autoboresight facility accurately aligns the tracker datum to the laser boresight. This facility can be used during flight to maximise the laser/tracker harmonisation accuracy. When the autoboresight function is selected the front window is rotated in pitch so that the sensor sightlines are pointing aft into the Pod. The combined laser/TI sightline is transmitted through the external window, reflected off a folding mirror and focussed by a paraboloid onto an absorbing target within the Pod. The laser is fired at the absorbing target causing a hot spot to appear on the target. This spot is observed by the TI and any error between the TI sightline graticule and the hot spot is detected by the tracker. The tracker measures the misalignment and stores it as a correction vector. A fraction of the laser energy is reflected back into the TV channel to permit calibration of the TV sightline graticule in a similar manner.

The front end is sealed to eliminate the risk of contamination and heat is transferred via an air to air heat exchanger to an Environmental Control Unit (ECU) located immediately to the rear of the front section. The rear section contains several electronic units and two power supply units and is cooled by forced air from the ECU. Access hatches in the external skin permit access to all the internal Line Replaceable Units.

The Thermal Imager is located entirely within the front section and comprises the scanner, electronics unit and optics. The scanner and electronics are based on the UK TICMII thermal imaging programme and are manufactured by GEC Sensors. Detector cooling is provided by a ... closed cycle cooling engine. The optics provides field of view change, focus adjustment and image ... Automatic thermal compensation of focus is provided.

The TV is a compact solid state CCD unit manufactured by GEC Ferranti. The camera is fitted with a single field of view compound lens assembly which matches the narrow field of view to the TI. The optical path is folded by means of a periscope and adjustable mirror and injected onto the common stabilised mirror at the front end of the Pod. The lens contains a derotation mechanism which is servo controlled.

The laser rangefinder and designator provides both target range and laser energy for target designation. The raw laser beam is expanded within the laser telescope to decrease the beam divergence and power density. The telescope also contains a focus mechanism to compensate for changes in temperature. The objective lens of the telescope and the folding mirror are shared with the TI. This ensures maintenance of accurate boresighting and is necessary to provide a compact design. The laser beam forms the primary optical boresight of the Pod and is aligned to the gimbal axes. Coding of the laser pulse repetition rate ensures it is compatible with the laser guided munitions currently in service

The tracker is an automatic dual mode device which operates on video from TI or TV. It calculates yaw and pitch errors between the target and the tracker boresight and outputs these to the steering servos. Both centroid and correlation tracking are available. The tracker is manufactured by British Aerospace Dynamics Division.

Sightline control maintains the sightline stable against vibration inputs and computes the correction terms to be applied to the gimbal servos to maintain the sightline on the correct target point.

5. INTEGRATION

The Pod maintains the sightline accurately on the target point by means of calculations based on the aircraft position, attitude and velocity vector. In order to ensure the highest accuracy, the computations must utilise the most accurate aircraft related data. Any delay between measuring the aircraft data and it being available to the Pod can result in degradation to the performance. It is essential that the system is fully integrated with the avionics and that the data transfer is managed to minimise delays.

A possible integration scheme is shown in Figure 8. It is assumed that the aircraft is fitted with an Avionics Data Bus and that the Pod is attached to this bus. Aircraft data can then be transferred directly from the INU to the Pod as an RT to RT transfer. Also shown is a Bus Interface Unit (BIFU) which interfaces such commands as mode control, slew control, laser fire and track which are operator activated.

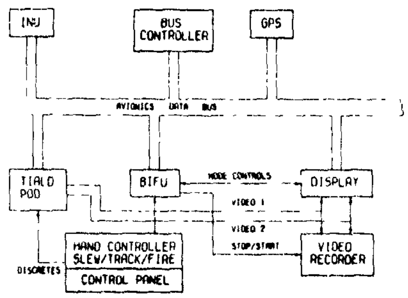

FIGURE 8 ; POSSIBLE POD INTEGRATION SCHEME

The diagram contains a GPS and it is felt that if GPS is available and properly integrated with the INU, very accurate target co-ordinates may be made available to the Pod for initial pointing. When alignment errors between the Pod and the aircraft are removed by suitable harmonisation procedures, the initial sightline pointing should be very close to the target and minimise the need for aim point refinement. This is a very important feature in the minimisation of crew workload.

6. RESULTS

The equipment has been subjected to extensive evaluation. The performance of both sensors has been measured under well controlled laboratory conditions. Performance for similar input conditions is comparable. The television sensor provides the same magnification as the thermal imager. The horizontal field of view is 3.6° but because additional active video lines are provided by the television, the vertical field of view is 2 7 compared to 2 4° for the TI. The predicted range performance in the narrow field for standard conditions and for a defined target is very similar for both sensors. Controlled flight tests have been carried out using bar targets and the predictions of the modelling checked.

Flight testing against a variety of targets covering a wide range of weather conditions has been conducted over several months. Results are very encouraging and show the value of both channels in providing complementary performance. Weather conditions could not be controlled, however situations were encountered in which TV offered better performance and on different occasions

favoured TI operation. As stated earlier, an attempt to fly against all conditions is clearly impractical and the results must be accepted as reflecting a limited subset of all conditions.

Two examples of comparative TV and TI video are shown in the photographs. These are simultaneous frames taken from a dual track recording made during a trials flight in the UK. The first set, Figures 9 and 10 show a bridge viewed from medium altitude. The TI frame also carries HUD symbology which was superimposed on this channel for recording purposes only. Both frames show similar information.

The second set, Figures 11 and 12, show a power station viewed from lower level. Again the TI channel carries HUD symbology. In this case differences between the two images are apparent. Attention may be drawn to the two storage tanks to the right of centre which are easily visible in the TI frame but are less visible in the TV frame. Also the collection of boats moored in front of the complex are much more easily visible in the TV frame than in the TI frame.

As mentioned earlier, various video super position schemes have been demonstrated in the laboratory. An example of simple video mixing is shown in Figures 13 and 14. These frames are the result of mixing the two images from the different sensors. Good registration is essential for such a scheme. For the bridge scene, the result does not appear to offer any particular improvement. For the power station scene, it would appear that the information content of the mixed video frame is greater than that of the separate sensor frames.

7. CONCLUSIONS

This paper has discussed the requirements for increased sensor performance and suggested that one solution may be to provide a dual sensor capability. The difficulties of conducting tests under realistic conditions are set out and the alternative of providing calculated performance based on recorded weather and target data suggested. Based on modelling for two locations in the Gulf region it is shown that TV can offer major advantages in hot humid conditions. An equipment providing a dual sensor capability is described and the results of carrying out trials flying in the UK are presented. These results are qualitative for the reasons discussed above but show the complementary nature of both sensors in aiding the target acquisition and aiming task.

8. ACKNOWLEDGEMENTS

The author gratefully acknowledges the support and assistance received from his colleagues in Electro Optics System Group of GEC Ferranti. Particular thanks are due to Steven Harding, John MacLean and Jeremy Copley of the Systems Modelling Group for their support and modelling assistance.

This work has been carried out with the support of Procurement Executive, Ministry of Defence

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DISCUSSION

DISCUSSOR : Col. **MATHE** (France)
(NU). What is the date of IOC (Initial Operational Capability) for RAF with the two sensors (IIR + TV) pod ?

AUTHOR'S REPLY :
(NU). The current contract field by GEC-Ferranti is to supply to the MOD single sensor thermal imaging pods. We confidently expect this to change soon.

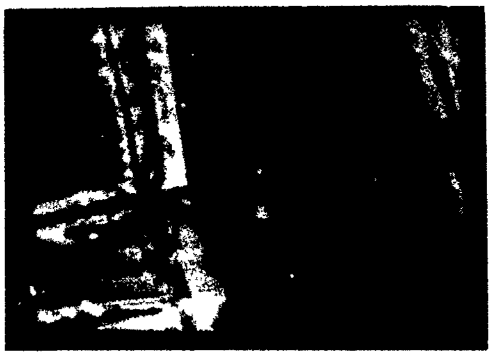

FIGURE 9 : BRIDGE FROM TV CHANNEL

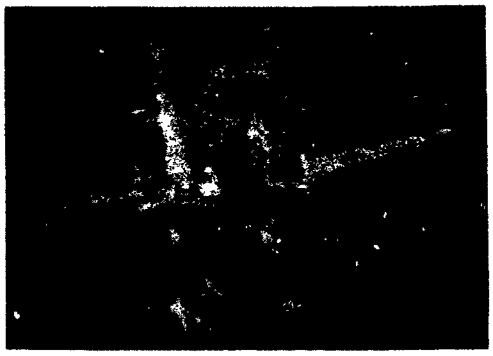

FIGURE 10 : BRIDGE FROM TI CHANNEL

FIGURE 11 : POWER STATION FROM TV CHANNEL

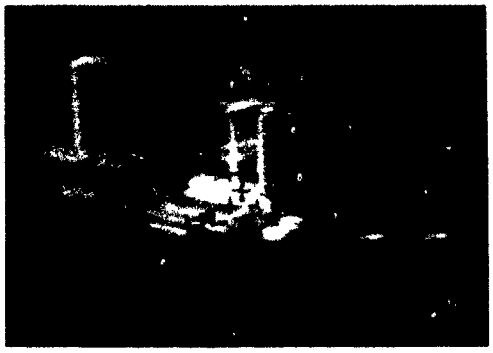

FIGURE 12 : POWER STATION FROM TI CHANNEL

FIGURE 13 : BRIDGE TV AND TI MIXED

FIGURE 14 : POWER STATION TV AND TI MIXED

Generic Modular Imaging IR Signal Processor

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Naval Weapons Center, China Lake, California 93555-6001

1. SUMMARY

We have developed a modular signal processor architecture that is suitable for many applications to meet real-time requirements and is adaptable to multiple uses. This generic modular architecture was developed and demonstrated in real-time hardware for representative filters and a target detection algorithm. Computer-aided design tools were used throughout the hardware development. An application-specific integrated circuit (ASIC) or other custom IC implementation can be used for actual production hardware

2. INTRODUCTION

Numerous enhancement, acquisition, tracking, and classification algorithms have been developed for imaging weapons systems to deal with various target scenarios. These algorithms have been evaluated in laboratory environments, but are computationally intense and require complex signal processors for real-time operation. Using imaging IR data for real-time missile guidance requires a system with very high data rates, low power dissipation, and small volume. Gate array or ASIC technology can transfer these designs from a laboratory simulation to a missile processor but at a high cost for each design. New requirements and algorithms are continuously being developed that require costly and lengthy redesign of signal processors. Different scenarios often require unique algorithms for detection and classification. Increasing funding shortfalls preclude independent signal processor development for every missile program.

3. OBJECTIVE

Our goal was to design and demonstrate an imaging IR signal processor architecture adaptable to a variety of applications. The technical concept is expandable to allow for future algorithm and IC developments. This approach can reduce production costs with algorithms embedded in adaptive ASIC designs. We conducted a laboratory demonstration of the signal processor using real-time video inputs. The resultant demonstration showed the capability of a modular architecture to handle various complex imaging IR signal processing algorithms in a real-time environment. Real-time capability is necessary to evaluate large amounts of imagery, for quantifying algorithm performance, and in testing new imagers. More importantly, the modular processor demonstrates that these algorithms can be run in real time and, therefore, offer the potential for inclusion in future weapons systems

4. MODULAR PROCESSOR

4.1. Signal Processor

Our signal processor takes a standard RS-170 video signal from an IR imager, VCR, or other source, digitizes it, processes it, and converts the signal back to RS-170 video for display. In typical tests the VCR is used to supply a source of video imagery, and to display processed results simultaneously with the original, as shown in Fig. 1.

4.2. System Architecture

The bus architecture is a high-speed pipeline. More compact implementations are possible, but the design we chose uses a modular system constructed for our prototype on standard wire-wrap cards, one card for each processing algorithm. The flexibility of this modular design allows evaluation of several different algorithms and expansion capability for future functions. Two types of pipelines were used, a simple one with very little overhead for each module and

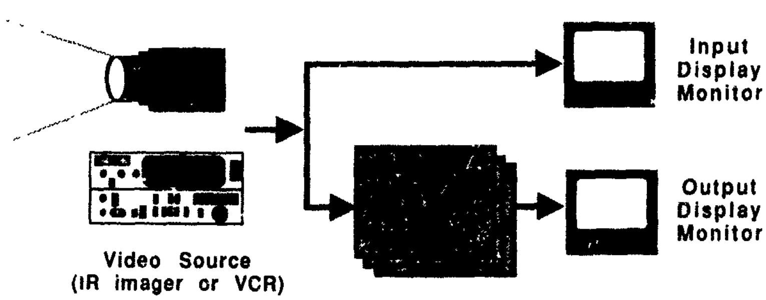

Fig 1 Typical test setup

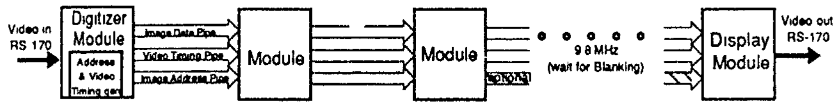

Fig 2. Simple pipeline system

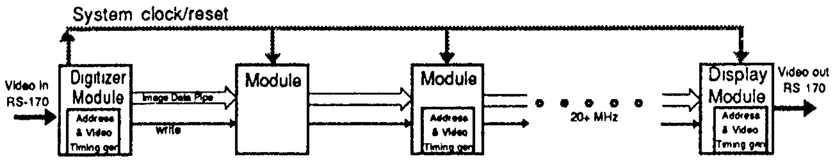

Fig. 3. Distributed pipeline system.

maximum processing speed (Fig 2), and a more flexible interface (Fig. 3) using first-in first-out (FIFO) buffers and reduced data lines (9 bits versus 33). The second design distributes the video timing and address generation to the modules that require it, but saves the transfer of that information between modules.

Both schemes were used in brassboard processors and fully tested. The distributed design required two additional ICs per module for interfacing. The two ICs are a FIFO memory chip and a programmable array logic (PAL) chip. Both of these chips use CMOS technology, have small power requirements, and take up little real estate. Using these two chips in tandem enabled us to reduce the necessary control logic to one bit This process required only a 9-bit data bus (8 bits of data and 1 bit for control). Advantages of the fully distributed system include fewer interconnections between modules, transfer rates between modules limited only by FIFO speeds, simpler module designs, and completely asynchronous timing. The advantage of using FIFOs is that data transfer rates are limited only by the current FIFO technology FIFO speeds and capacities increased 200 to 400% in the last year (currently 20 to 50 megahertz (MHz)). This design can be used in a variety of different speed imaging IR signal processing systems because no set system data rate exists As future algorithms increase in complexity, asynchronous timing for each module ensures that the module implementing the algorithm can increase its processing speed without regard to other modules.

4.3. Distributed Power

Both schemes use a distributed power system with voltage regulation and conversion handled locally by each module. Distributed power greatly simplifies expansion of the system as modules can have unique requirements for voltages, power, noise, and reliability. A central supply could not be designed to handle any and all features that an added module might need. The power busing also is greatly simplified as less current is needed at higher voltages and only two voltages need to be distributed. Because the system load is partitioned, a failure in one converter affects only that portion of the system, has limited impact on total performance, and provides weight and cost savings. Redundant power sources can be added for critical functions without the significant cost and weight penalties for a redundant central power system A central bulk power supply cannot respond to fast changes in load requirements on a large power bus; distributed converters can The quality of distributed power is kept clean by isolating each module or subsystem and by using separate power and ground planes

5. MODULES

We built a total of 11 different modules including a digitizer and a display module for each of the two system architectures We implemented several image enhancement techniques to improve image contrast and content for a human observer (Ref 1), and implemented a target detection technique (Ref 2) in a module. Future plans are to design and fabricate a tracking module

5.1. Digitizer

One basic function necessary to process imagery digitally is to digitize the image. The incoming video signal (from IR imager or VCR) is digitized to 8 bits and 512 pixels per line This resolution determines the system clock rate of 9 8 MHz (Equations 1 and 2).

$$(1/(30 \text{ frames/s} \times 525 \text{ lines/frame})) - 11.1\ \mu s \text{ blanking} = 52.1\ \mu s \text{ active/line} \quad (1)$$

$$(512 \text{ pixels/line})/(52.1\ \mu s \text{ active/line}) = 9.8 \text{ MHz} \quad (2)$$

More precise digitization is unnecessary in most applications because a human operator can distinguish only 6 to 7 bits of grey level on a video monitor (Ref 3) Digitizing is performed by a hybrid analog-to-digital (A/D) converter,

Analog Devices AD9502, which will accept RS-170 video directly. Fast CMOS logic is used to convert the sync signals, supplied by the AD9502, to appropriate horizontal and vertical blanking signals and other video timing signals, which are needed later to convert back to analog video. Although a final configuration would use the signal directly from the focal-plane array and not RS-170, we used RS-170 because of its compatibility with many prototype IR arrays and standard video equipment.

5.2. Display

After processing the digitized image, reconversion to an analog video signal is necessary to display the image. This reconversion is accomplished using the AD9701 digital-to-analog (D/A) converter. This component will construct a video signal from the 8-bit digital pixel information and video timing signals. Equalization pulses, which are not needed to display the image, are not added to the sync signal; these pulses can easily be added with additional logic. We used a 16R4 programmable logic device (PLD) to implement latch-and-inverter functions for the simple pipeline, and used several 22V10 PLDs and counters for the distributed design to generate the video timing signals.

5.3. Bit Slicing

A crude but sometimes useful technique for improving contrast is bit slicing. The bit-slicing function is so simple that no active devices are required to implement it. Everything is done with one eight-position switch. The switch selects the bit to be 'sliced;' that bit is connected to all the bits of the output. As an example, suppose an input pixel has a grey level of 123 and we are slicing the 4th bit (Fig. 4). 123 has a binary value of 01111011. Because the fourth bit is a 1, all the output bits will be 1s. The output pixel would have a grey level of 11111111 or 255, which is a white pixel.

5.4. Windowing

The resolution of the IR arrays we used is less than the resolution we digitize to, resulting in an image that does not fill the entire video frame. Also, symbology was added to some imagery that interferes with statistics and histograms. A windowing capability is needed to exclude portions of the image we are not interested in (i.e., outside the sensors image or symbology), as shown in Fig. 5.

Windowing is performed by creating signals similar to the video blanking signals by counting horizontally and vertically to the desired dimensions of the window. To simplify changes in window dimensions and to minimize the number of components used, we used two reprogrammable PLDs.

5.5. Contrast Enhancement

Contrast is one of the most important factors when presenting imagery to a human observer. Much of the IR imagery we collected suffers from a lack of contrast. One simple improvement technique is to stretch the contrast so that the full range of grey scales from black to white are used. The implementation used compares each pixel value in the image to find the maximum and minimum grey levels; then, uses an INTEL 8751 microcontroller to compute a mapping function or look-up table (LUT) to transform each grey level to one that uses the entire available range of grey shades. The LUT is performed using a dual-port static RAM that allows us to fill the RAM with the LUT values on one port, and asynchronously to use each incoming pixel grey-shade value to address (look up) a grey-shade value for the output pixel on the other port (Fig 6).

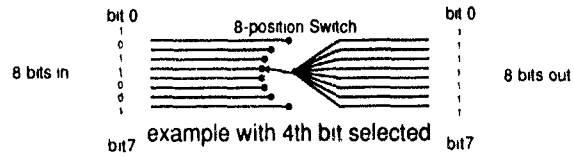

Fig 4 Bit slicing.

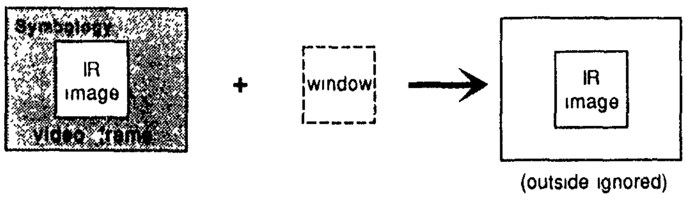

Fig 5. Windowing

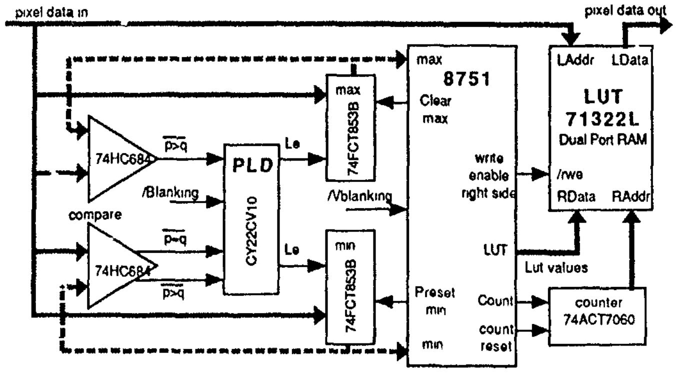

Fig. 6. Contrast enhancement scheme.

5.6. Histogram Equalization

A second approach to the contrast problem is to modify the distribution of grey levels to spread out certain areas and compress others. One commonly used technique is histogram equalization The histogram (grey-level distribution) of the image is computed and used to create a mapping function, or LUT, that will spread the grey-level distribution equally over all the available grey levels—thus, histogram equalization. Truly equal distribution is impossible because of the limits of finite arithmetic, but the results can significantly enhance contrast in an image.

Histogram equalization is a complicated technique to implement. The histogram is computed using an accumulator RAM that uses the incoming pixel grey-level values for addressing, and increments each location every time the location is addressed (Fig. 7). The accumulated histogram is computed by starting at grey level 0 (black) and adding up or accumulating all the previous histogram values for each grey level (Fig. 8). The accumulated histogram is converted to a histogram equalization transfer function or LUT by rounding off the 16 bit or 216 range of the accumulated histogram to an 8 bit or 256 range (Fig. 9).

We used an LSI Logic L64250 Histogram Hough Processor (HHP) chip to perform histogram equalization. This device contains the needed accumulator RAM and LUTs. We used a programmable sequencer, Advanced Micro Devices (AMD) PMS14R21, to initialize the HHP chip using a state machine design.

5.7. Frame Averaging

A very effective noise-reduction technique is frame averaging. The current input image is added (averaged) with a past image, which is stored in memory, to form an output image The output image becomes the image stored in memory for the next image. To keep the memory from overflowing because of accumulation, a division of the pixel value by two is necessary. The simplest way to divide the pixel by two is to drop the least significant bit (LSB) of the 9-bit

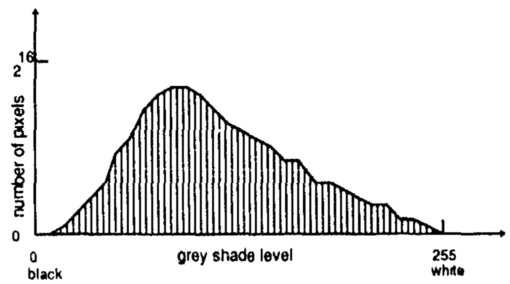

Fig 7. Histogram

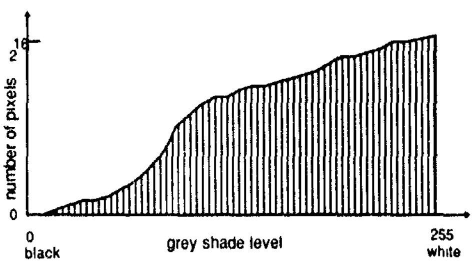

Fig 8 Accumulated histogram

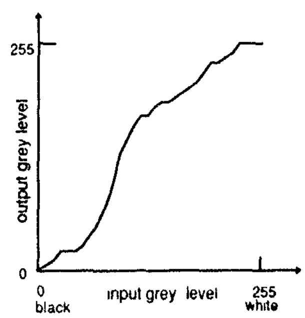

Fig 9 Histogram equalization LUT

sum. Large static RAMs are needed to store the image; two image memories are used (Fig. 10) because of the need to read and write for each pixel

5.8. Median Filter

A useful technique in removing noise is median filtering. A small group of pixels is sorted by value and the middle value chosen to replace the center pixel. This process eliminates high frequency noise in an image and is often superior to averaging techniques. A nonlinear filter was implemented using an LSI Logic 64220 rank value filter (RVF). The RVF performs all the comparisons necessary to sort pixels in a configurable 64-pixel window at speeds up to 20 MHz. A simple 1-by-5 window was chosen for this application and the median value chosen, although minimum or maximum filters also can be implemented. A simple state machine design implemented with standard 22V10 PLDs is necessary to initialize the RVF chip

5.9. Target Detection

A representative target detection technique using statistics obtained from a co-occurrence matrix was selected and implemented in one of our modules. The co-occurrence matrix is the joint grey-level distribution of an image (Ref 4). Basically, each pixel is compared to its neighbor and a special histogram is made Co-occurrences of grey levels (identical neighbors) represent homogeneous regions in an image. Assuming that man-made targets in an IR scene, such as ships, are more uniform in grey shade than the background, the co-occurrence matrix provides a method to detect these targets In simple scenes, the largest object is defined as the background, and the second largest as the target or targets. The co-occurrence histogram is divided into two parts to segment the target(s)

To implement this algorithm, only a portion of the co-occurrence matrix needs to be computed. The co-occurrences of the same grey levels and those that differ by two were chosen based on empirical data. For each pixel, a comparison is made between that pixel and the previous pixel. If the pixels are equal, or differ by only two grey levels, that pixel value is added to a histogram computed by two LSI Logic L64250 HHP chips (as described in section 5.7). Two chips are needed because a 16-bit histogram will be read out. The histogram of co-occurrences is read out by an AT&T DSP16A digital signal processor (DSP) chip and the histogram segmented into target and background. A threshold for segmentation of the image is calculated and the image is processed accordingly to highlight potential targets. While co-occurrence histogram data take one frame to accumulate and additional time to process, the threshold is used on the current pixel data even though the threshold is based on statistics from the previous frame. This technique avoids costly frame buffers and the associated delays. Scene statistics do not change significantly from one frame to the next.

6. RESULTS

All boards functioned as anticipated. Video data at real-time rates (30 frames/second) were fed into the boards, and the output of the boards was real-time enhanced imagery. A major advantage of this system is the flexibility provided by having each function on a separate board or module. This modularity allows many configurations and combinations of algorithms to be tested on a variety of imagery. The architecture is such that other functions—tracking or target identification—can be added to the filters and target detection modules. If this design were chosen for future imaging weapons systems, significant savings could be realized in later modifications and other configurations. This modular processor can now be considered an off-the-shelf design available and adaptable to many applications.

7. ACKNOWLEDGEMENTS

This work was performed as part of the Air-Launched Weaponry Technology Program from1988 to 1990.

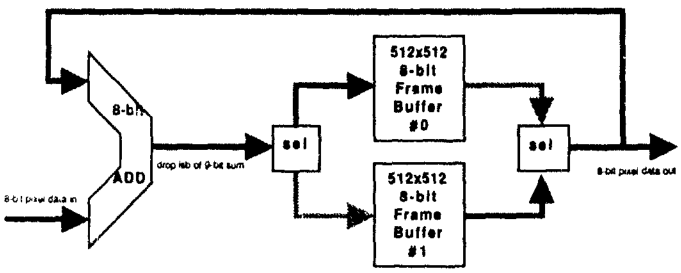

Fig 10 Frame average diagram

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DISCUSSION

DISCUSSOR : **Mr T. FERRE** (France)
(NU). Is your Signal Processor capable of processing other data than RS.170 ?

AUTHOR'S REPLY :

(NU). Yes, the processor design and most of the modules can handle other video formats at speeds up to 20 MHz. The digitizer and display modules would need to be changed to handle PAL, SECAM or other military formats, but the rest of the modules and the system architecture can remain the same.

Image Enhancement of Infrared Uncooled Focal Plane Array Imagery

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Naval Weapons Center
China Lake, California 93555-6001

SUMMARY
Several simple, low-cost algorithms have been explored for use in the enhancement of imagery produced by uncooled focal plane arrays (UFPA). These algorithms address the main problems that UFPA-produced imagery typically demonstrate In addition to enhancing UFPA-produced imagery, all these algorithms are simple and allow for inexpensive hardware implementation.

1. INTRODUCTION

The number of applications requiring low-cost infrared imagers has increased. Many of these applications use, or plan to use, infrared uncooled focal plane arrays (IRUFPA) to meet these imaging requirements Many advantages to using IRUFPAs exist (such as low cost, no required cooling, and no complex mechanical-scanning devices), but one disadvantage has always been the quality of IRUFPA-produced imagery IRUFPA imagery commonly suffers from a lack of image contrast and resolution.

Classical image-processing and enhancement techniques (Ref. 1-4) can be used to improve the quality of IRUFPA-produced imagery. In addition, these techniques can be kept simple enough to run the algorithms in real time without expensive hardware implementations and still achieve large quality improvements

2. UFPA-PRODUCED IMAGERY

Uncooled focal plane arrays are an inexpensive and highly reliable alternative to expensive infrared-imaging systems. Uncooled focal plane arrays operate at room temperature, eliminate expensive cryogenic-cooling systems, and eliminate expensive and complex scanning devices. Expense is not the only benefit of the uncooled infrared-imaging devices. Reliability also is improved because the cryogenic-cooling systems and the complex scanning devices are often sources of problems for infrared imagers.

The UFPA imagers are attractive because they are highly reliable, low-cost devices, but the raw images they produce often is not good enough for many applications. After looking at and analyzing a number of UFPA-produced images, we found several problems One problem is low resolution, which is caused by manu-facturing large dense arrays. Although some techniques exist to improve low-resolution devices, we opted not to explore this avenue of enhancement.

The imagery made by a low-sensitivity imager often displays a low-contrast differential between objects in the imagery and the background Many techniques for contrast enhancement were explored and are described in the next section.

The last imagery-display problem that we looked at is a low signal-to-noise ratio. In other words, the imagery is very noisy. There are two types of noise that plague the UFPA-produced imagery. The first is random noise and the second is fixed-pattern noise. We effectively eliminated random noise from UFPA-produced imagery and will describe this process in the next section Fixed-pattern noise, on the other hand, is more difficult to eliminate.

3. UFPA IMAGE ENHANCEMENT

Numerous algorithms are available to perform contrast improvement or noise reduction. We wanted to produce the best imagery possible, but more importantly, we wanted to select algorithms that were simple, inexpensive to implement in real-time hardware, and effective. This selection allows us to combine an imager/image-processing hardware into one small package and still keep the cost below that of other infrared systems.

3.1. Contrast Improvement

Most of the algorithms available for contrast improvement are simple and easy to implement at low cost in real-time hardware, but we wanted an algorithm that brought out the most detail in UFPA imagery (Fig. 1). Some of the algorithms, which improved the contrast, reduced the amount of detail a viewer could distinguish. Three of the algorithms we looked at are discussed below.

Figure 1 Original UFPA-produced image

3.1.1 Bit slicing

Images are stored in a computer as arrays of discrete samples called pixels (Fig. 2). Each pixel is represented as an n-bit value. The image array also can be described as being an array of bits that is n-planes deep (Fig. 3). An example would be an image of 512 by 512 pixels in size. Each pixel is digitized to 8 bits (a total of 256 different gray shades can be represented by each pixel). We could also imagine this image as being 512 by 512 bits in size by 8 planes deep. Bit slicing is a simple and effective method of contrast enhancement. If we choose one plane and pull it out of the image, much like pulling a card from a deck, and display it as a binary image (a 0 bit displays black, a 1 bit displays white), we improve the contrast of the image. The trick is to choose the correct plane.

Not all information is represented in each of the bit planes. For instance, the least significant bit plane will look like white noise because only small changes in gray shade across the image usually are represented. Larger changes in gray shade will be represented in

the more significant bit planes until the most significant planes are reached These planes often are seen as all black or all white. It is important to choose the plane that contains the information you most want to see (Fig 4)

Bit slicing is an effective, inexpensive, and simple method of contrast enhancement, but eliminates too much of the image detail and was not selected in the final analysis.

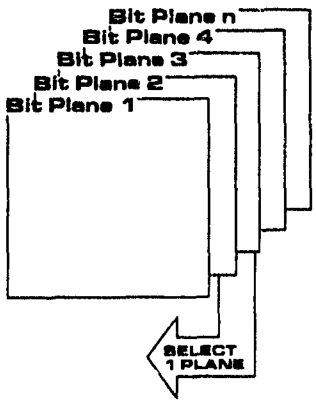


Figure 2 Stored-digitized image

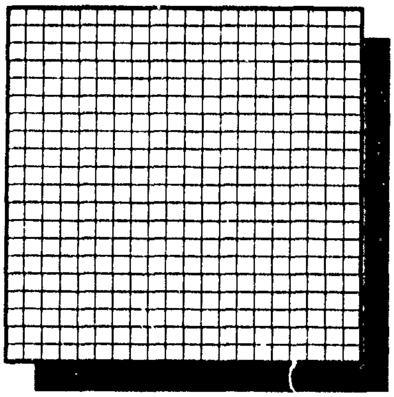


Figure 3 Image stored in planar format

Figure 4 Selected one-bit plane displayed as binary image

3 1 2 Histogram equalization

Histogram equalization is more complex than bit slicing. However, the algorithm is more effective at enhancing the contrast of an image because more of the image's detail is preserved. The first operation is to compute the image histogram; that is, plot the gray level probability-density function on a two-dimensional graph with X representing the gray scale and Y representing the number of pixels of a specific gray shade in the image. Fig. 5 is a typical histogram of a low-contrast image; note that the gray values are grouped toward one side of the grav scale. To equalize the histogram, a look-up table (Fig 6) is computed so that the gray area is stretched from its typical bell-shaped curve into a more linear format (Fig. 7). This technique spreads the gray area over the entire range of gray shades available to the display, and results in an image of much higher contrast. Temperature variations within the image show up and the image content is more distinct (Fig. 8).

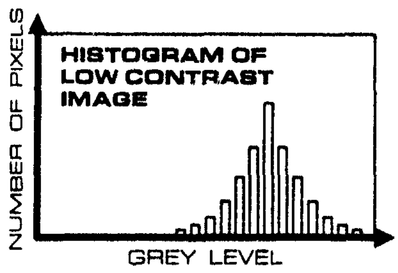


Figure 5 Histogram of low-contrast image

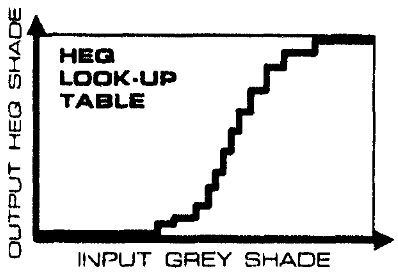


Figure 6 Look-up table used to flatten image histogram

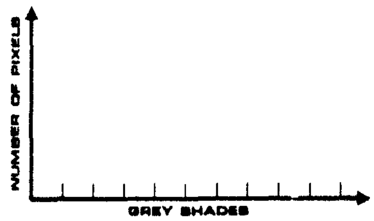


Figure 7 Flattened histogram

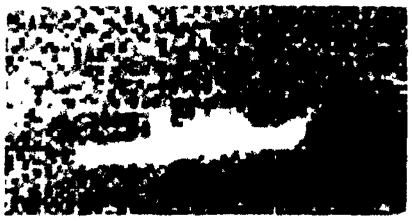


Figure 8 Image after histogram equalization

The histogram-equalization algorithm is a fast and effective contrast-improvement algorithm. However, the algorithm described below proved to be more effective in preserving image content.

3 1.3. Contrast enhancement
Contrast enhancement is a technique similar to histogram equalization. However, the bell shape of the original histogram's curve is preserved. A look-up table (Fig. 9) also is used to distribute gray shades more evenly over the entire range of the display to enhance image contrast (Fig. 10).

Contrast enhancement proved to be the best of the algorithms we tried. We implemented the algorithm on an image processor, analyzed the results in non-real time, ported our algorithms to a real-time system built from off-the-shelf components, and analyzed the results. Currently, we are working on some special-purpose hardware using VHSIC and ASIC technologies to perform the algorithm in real time.

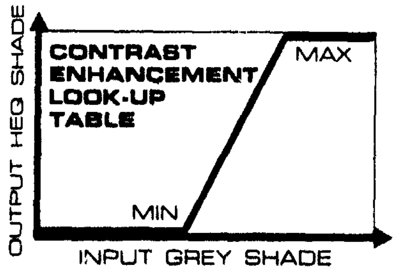
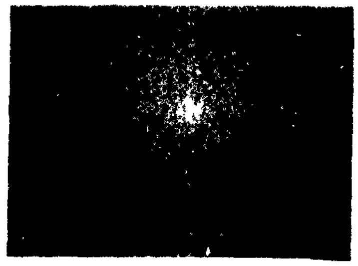


Figure 9 Look-up table used during constrast enhancement

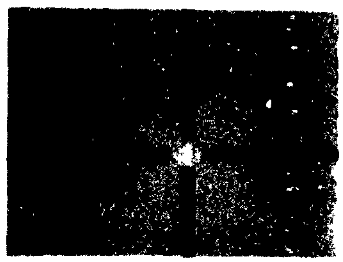
Figure 10 Image after contrast enhancement

3.2. Noise Reduction
Many available algorithms, such as low-pass filters, median filters, Fourier filters, and integration techniques, will reduce the noise in an image; all are well documented and many work very well We had great success with the Fourier analysis and the image-integration techniques. The low-pass filters blurred the image and eliminated too much of the detail that we wanted to keep. Median filters were not effective because of the low resolution of the image-required pixel replication that expands the image.

3 2 1. Fourier analysis
Fourier analysis proved to be an effective method of filtering the noise from the image The two-dimensional Fourier transform of the original image was computed giving an image of the frequency domain. A band-pass filter, which filtered out the high-frequency noise, was applied to the two-dimensional fast-Fourier transform (FFT). Then the inverse Fourier transform was applied to the filtered frequency-domain image and the filtered image was the result (Fig. 11).



(a) FFT of image



(b) FFT after band-pass filter opertion

(c) Image after Fourier analysis and contrast enhancement

Figure 11 FFT, filtered FFT, and resultant image

Fourier analysis is a good algorithm to use in filtering UFPA imagery. However, we wanted an algorithm that would preserve more of the image edge and detail information. Image integration filled this request.

3.2.2 Image integration

The technique of image integration (Fig. 12) is used to eliminate (average out) random or white noise typically seen in UFPA-produced imagery. During this process new video frames are added to the contents of the image memory, which contains the running average of the video memory. The sum of the new video frame and the averaged images is divided by two and displayed as the corrected image. At the same time, the result is reloaded into image memory to await the addition of the next new video frame. For better results, the running average of more than two images can be displayed (Fig. 13).

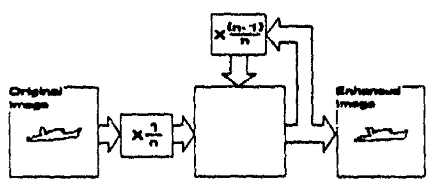


Figure 12 Flow diagram of image-integration algorithm

Figure 13 Image after image integration

Image integration has faults. First, if the imager is moving, the resulting image tends to blur, which is more apparent when the number of frames is increased. Secondly, the image integration technique does not remove the fixed-pattern noise seen in UFPA imagery. In fact, image integration tends to enhance fixed-pattern noise. The benefits of the algorithm seem greater than the drawbacks. We are analyzing the algorithm using a non-real-time image processor and an off-the-shelf real-time system, and are working on special-purpose hardware to perform the algorithm.

3.3. Combinations

We identified two algorithms that address separate problems with UFPA-produced imagery, and wanted to see how they performed together. Could they be put together and retain their simplicity and effectiveness? We discovered that the combination of image integration followed by contrast enhancement works extremely well (Fig. 14).

Figure 14 Image after image integration and contrast enhancement

4. CONCLUSIONS

Our tests with the image processor and our real-time system proved that UFPA-produced imagery can be improved significantly by using simple, easy to implement, fast image-processing algorithms like the combination image-integration/contrast-enhancement algorithm. We are continuing exploration of different image-processing techniques to find more effective yet simple solutions to the UFPA-imagery problem.

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DISCUSSION

DISCUSSOR: Mr J. DANSAC (France)

(NU).
1) What is the type of Focal Plane Array ?
2) What is the application ?

AUTHOR'S REPLY :

(NU).
1) Ferroelectric Focal Plane Array (FPA)
2) Possible applications :
- Rifle sights
- Seekers / Missile guidance.

Target Cuing—A Heterogeneous Neural Network Approach

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SUMMARY

Autonomous analysis of complex image data is a critical technology in today's world of expanding automation. The growth of this critical field is slowed by problems in traditional image analysis methods. Traditional methods lack the speed, generality, and robustness that many modern image analysis problems require. While neural networks promise to improve traditional techniques, homogeneous neural network systems have difficulty performing all the diverse analysis required of an autonomous system. This paper proposes a dual-staged, heterogeneous neural network approach to image analysis; specifically, a way to solve the target cuing problem.

1. INTRODUCTION

The target cuing problem can be separated into two distinct operations: feature extr^ction and feature classification. Experimentation has shown that biologically inspired neural networks perform feature extraction from raw imagery extremely well, but are not as good at classifying those features once extracted. Back-propagation networks can be taught to reliably classify image features once the features have been extracted from the original image. However, teaching these back-propagation networks to extract features from a raw image on their own is very difficult.

We propose a dual-staged, heterogeneous neural network approach to autonomous target cuing. Stage 1 of the target cuing algorithm uses biologically inspired neural networks to extract features from raw imagery.

Stage 2, a back-propagation neural network, accepts those image features and performs the final classification. The result is a determination as to whether a target exists in a specific portion of the image, based on the features extracted by the biologically inspired networks. Fig 1 illustrates this approach.

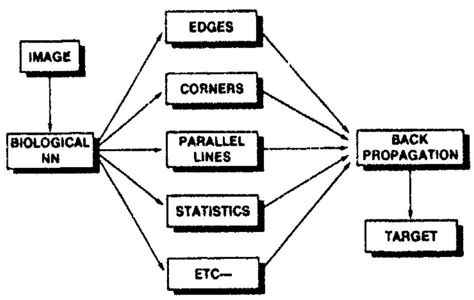


Fig 1 Heterogeneous approach

2. FEATURE EXTRACTION STAGE—BIOLOGICALLY INSPIRED NEURAL NETWORKS

2.1. Definition

The feature extraction stage is implemented using any number of small biologically inspired networks, one for each feature you wish to extract. The definition of a biologically inspired neural network, for the purpose of this paper, is a network that extracts any low-level feature. The term biologically inspired is based on work that seems to demonstrate that biological vision systems perform similar feature extraction operations (Ref. 1). None of the networks discussed in this paper are morphologically similar to biological systems. Examples of networks used to perform this type of low-level feature extraction include Hopfield, forward-propagation, and back-propagation networks.

2.2. Features To Be Extracted

Many low-level features exist that can be used to represent, segment, and explain raw input imagery. Several low-level features clearly have more influence in the image understanding process and were selected as features we wanted to use in our target cuing system. These features include directional edge features, endpoint features, corner features, low-level regional statistics, regional textural statistics, and motion.

Directional edge and endpoint features were extracted using a combination of forward-propagation networks arranged in a two-layer configuration. Layer 1 (Fig. 2) is constructed of forward-propagation networks and is used to extract the edge gradient information

In the Layer 1 forward-propagation network, specified inputs are taken from the raw image in parallel.

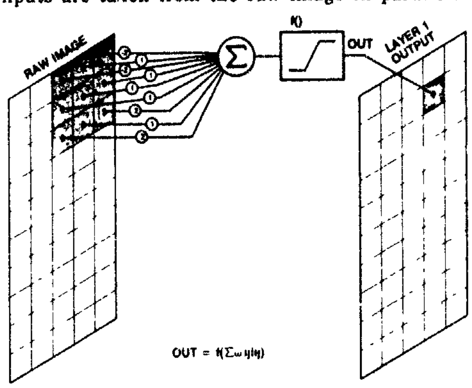


Fig 2 Layer 1 forward-propagation network implementation of the Laplacian

Then, these inputs are multiplied by weights associated with each line and summed. The result of the summation is put through a nonlinear transformation. The function of the forward-propagation network is determined by the inter-connections, the weights set on each interconnect, and the output transformation.

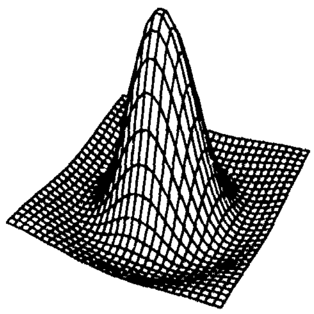
The Layer 1 interconnection matrix is set using a Laplacian of Gaussian operator.[1] The equation for the Laplacian of Gaussian operator is

$$\frac{-1}{\pi\sigma^4}\left(1-\frac{r^2}{2\sigma^2}\right)e^{\frac{-r^2}{2\sigma^2}}$$

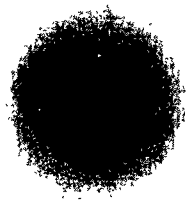
where σ is the standard deviation of the Gaussian and r is the radius. The reason for using the Laplacian of a Gaussian is that edges in all orientations are extracted in a single step as compared to directional edge detection techniques like the Sobel edge operator. The Laplacian of Gaussian operator is shown in Fig. 3.

The edge information computed in Layer 1 is put through Layer 2, which is composed of 20 directionally tuned forward-propagation networks in parallel. Each network in Layer 2 acts like a filter, eliminating all edge segments not oriented in the tuned direction.

The weight matrices for each of the directionally tuned networks are computed using the back-propagation algorithm. Edges in all orientations are used as input to an untrained network. Edges of various contrast, noise, and slope are also used to train the directional



(a) Three-dimensional representation



(b) Two-dimensional representation

Fig 3 Laplacian of Gaussian kernel

networks. After the network weights have been trained, the weights are saved and then used in the model. Ref. 2 contains additional information on the backpropagation algorithm used for setting the directional edge filter weights. Desired responses for each of the inputs are developed for each oriented network.

Figure 4 represents the entire two-layer process.

Corner features are extracted using a forward-propagation network with sigma pi connections (Fig. 5). The endpoint features extracted in Layer 3 are input to the corner feature network. Fig. 6 shows this process.

At this time, low-level regional statistics, regional textural statistics, and motion have not been integrated into the model; therefore, they will not be discussed further.

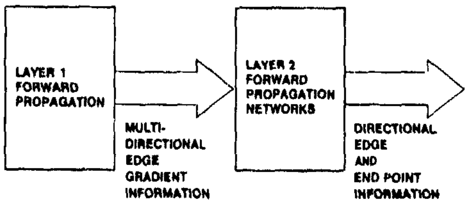


Fig 4 Low-level feature extraction network

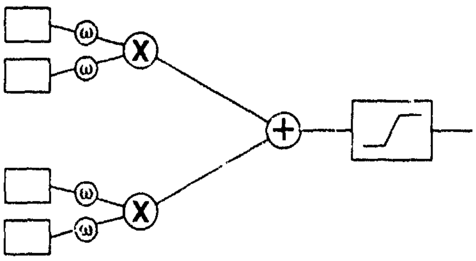


Fig 5 Sigma pi network

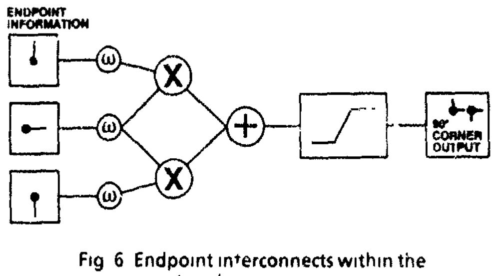


Fig 6 Endpoint interconnects within the sigma pi network

3. BACK PROPAGATION—MADALINE III

After Stage 1 has extracted the low-level image features, Stage 2 analyzes the features to determine if a target is present in the field of view. The analysis is performed using a number of back-propagation neural networks trained with the MADALINE III or back-propagation learning rules.

3.1. Architecture

The Stage 2 architecture (Ref. 3) breaks the image feature space into a number of small, medium, and large overlapping circular regions and assigns an identical (in terms of weight and architecture) back-propagation network to each of the circular regions (Fig. 7). Feature space is a two-dimensional object that contains extracted image features, which are spatially correlated with the image from which they were extracted. One back-propagation network is responsible for analyzing only those features extracted from its assigned region. Enough small region/back-propagation network combinations exist to cover the entire image. Also, enough medium and large combinations exist to fully cover the entire image. This arrangement of various sized segments gives the model its scale and translational invariance. Various scales can be achieved by changing the number and size of the regions.

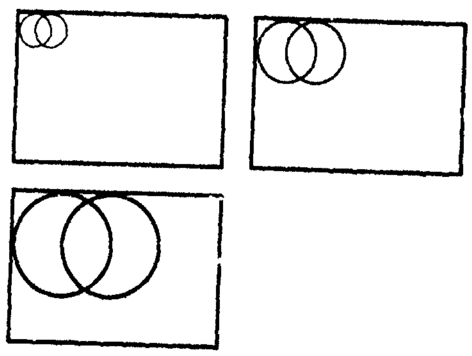


Fig 7 Segmentation of image feature space into a small, medium, and large area

Each circular region and its associated back-propagation network is termed a column. Each column is broken into four layers Layer 1 is a forward-propagation network used to collect the low-level features computed in Stage 1 and feed the features to Layers 2 through 4. Layers 2 through 4 are a back-propagation network trained with the MADALINE III or back-propagation learning rule. Layers 2 through 4 are responsible for analyzing the features and determining whether the features indicate target or background.

Layer 1 of Stage 2 is segmented into 19 circular subregions (Ref 3), each separated by the radius r. Fig. 8 shows the placement of each of these 19 subregions

Each of these 19 subregions contains one neuron per feature extracted in Stage 1 All neurons are located at the center of their circular subregion. The response of each neuron indicates whether that feature exists within the subregions field of view; and if the feature exists, how far the feature occurs from the center of the subregion. The equation used to compute the neuron response is

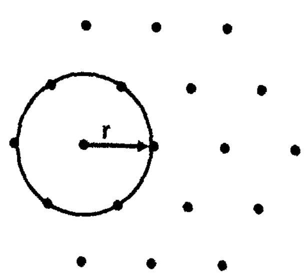


Fig 8 Placement of 19 subregions within a column

$$R = 1 - (d/r)^{0.5}$$

where R equals the response, d equals the distance from the center of the subregion to the feature, and r equals the subregional radius. Then, R is put through a sigmoidal function before being put into the Layer 2 back-propagation network.

The number of interconnects between Layers 1 and 2 is 19 times the number of features extracted in Stage 1. Layer 2 feeds into Layer 3, which contains 10 neurons; Layer 3 feeds into Layer 4, which contains a single neuron. The Layer 4 neuron indicates whether or not a target is within the columns field of view. Fig. 9 shows Layers 2, 3, and 4 of Stage 2.

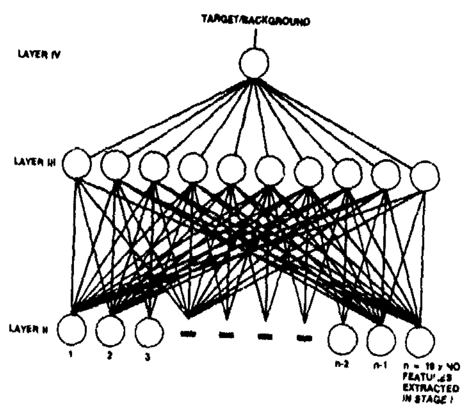


Fig 9 Layers 2, 3, and 4 of Stage 2

3.2. Teaching the Back-Propagation Networks

Once the model has been constructed, the back-propagation networks must be trained. All the back-propagation networks contain identical weight sets, so only one column needs to be trained. Then, the weights are copied to all the remaining columns. Representative background/target sets are displayed to the network and the weights are adjusted to give the desired results.

Layers 2, 3, and 4 of Stage 2 were decoupled from the remaining model to decrease the time used to teach the back-propagation network. Representative data were displayed to Stage 1 and Layer 1 of Stage 2, and the outputs stored in data files. Then, the Layer 2 back-propagation networks were taught using the prestored feature data as input, which eliminated the need to recompute the feature data each time the same training set was displayed to the back-propagation network.

4. RESULTS

Several experiments were performed to validate various portions of the model described. Results have been obtained on binary character image data as well as on poor quality imagery of a bridge Results of these experiments are shown in Figs. 10 through 12. We have been able to successfully recognize characters

in an image of text. Initial results on the poor quality bridge imagery are promising; however, more work needs to be done. The integration of additional features will be the focus of much additional work.

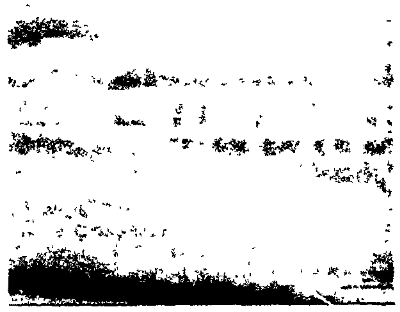


Fig 10 Raw bridge image

(a) Raw image rotated 0 degrees, output of vertical, horizontal, and 45-degree filters.

(b) Raw image rotated 45 degrees, output of vertical, horizontal, and 45-degree filters

Fig 11. Experiments of Layer 4 of Stage 1, directional and endpoint filters

Fig. 12. Bridge image after Layer 4 of Stage 2 Brighter pixels in this image indicate a higher confidence in that pixel belonging to a target

5. CONCLUSIONS

Experimentation has shown that biologically inspired neural networks extract features from raw images very well, yet perform poorly when required to use those same features to classify the pixels as belonging to a target or to the background. Back-propagation networks are good at solving the feature classification problem, but perform poorly with the feature extraction problem. The solution is to use both network architectures: the biologically inspired networks to perform the low-level feature extraction, and the back-propagation network to perform the classification of those features.

Computer simulations of this heterogeneous neural network are being developed and tested. While initial results indicate great promise, much work remains. Of the remaining work, integration of additional features is most important and will provide the greatest challenges and advances

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Target Detection Using Co-Occurrence Matrix Segmentation and Its Hardware Implementation

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1. SUMMARY

A number of acquisition, tracking, and classification algorithms have been developed to deal with various image processing problems in the laboratory. Typically, these algorithms are too complicated to implement in a low-cost, real-time processor. Using image data in many real-time applications requires a system with very high data rates, low power dissipation, and a small packaging volume. We developed a processor architecture suitable for these applications (Ref 1), and adapted and demonstrated a co-occurrence matrix target detection algorithm (Refs 2 and 3) in computer simulation and real-time hardware.

A histogram or grey-level distribution is often used to select a threshold for image segmentation. This technique is often inadequate as the histograms tend to be noisy and exhibit many small peaks. Co-occurrence matrix-based segmentation allows homogeneous regions of an image to be identified and separated from a cluttered background. Results are shown for target segmentation using representative infrared imagery and real-time hardware.

2. INTRODUCTION

Our goal was to develop a method for detection of man-made targets in IR scenes. The application required detection to be independent of the polarity of the image and independent of rotation. The approach had to be realizable in real-time hardware and compatible with size and weight restraints. We made a laboratory demonstration of the detection algorithm using a general-purpose image processor. The resultant demonstration showed the capability of detecting targets. Real imagery was used and the results were promising. We made an architectural design to implement the algorithm in hardware, simulated the feasibility of the approach, and made a detailed hardware design. A prototype system has been fabricated and tested.

3. CO-OCCURRENCE MATRIX

3.1 Scene Description

The co-occurrence-based target detection technique uses statistics obtained of the homogeneous regions in an image. Man-made objects, such as ships, are usually uniform in grey shade. However, the background is full of brush, trees, and other objects that change grey level rapidly. For ship images, the sea reflects the sky at different angles, which makes a changing background (Fig. 1). A co-occurrence matrix provides a method to detect the homogeneous regions. In simple scenes, the largest object is defined as the background, and the second largest as the target or targets. Because the target differs in temperature from the background in most IR scenes, the target can be separated by using a threshold. Typically, a threshold is found by examining the grey-level distribution and calling the largest peak the background, and calling the second largest peak the target. Often noise or lack of contrast will obscure the histogram peak corresponding to the target. The target peak is still present, just obscured. A target separation threshold can be found by using a portion of the co-occurrence matrix to create a histogram representing constant grey shade areas of an image.

Fig. 1 IR image.

3.2 Co-Occurrence Matrix Definition

The co-occurrence matrix is the joint grey-level distribution of pixel pairs. $P_{d\phi}(i,j)$ is the relative frequency with which two pixels occur in the image. One pixel is grey level i and one is grey level j and they are separated by distance d in direction ϕ. In our case, the distance d is always one and the direction ϕ is zero degree to represent adjacent pixel pairs in one line. Other

co-occurrences can be examined, but we only used this one for our application to minimize calculations. A sample co-occurrence matrix is shown in Fig. 2.

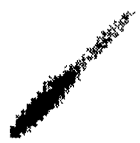

Fig 2 Co-occurrence matrix

3.3. Co-Occurrence Histogram

To eliminate nonhomogeneous regions from consideration, we only need to find the portion of the matrix along the diagonal. This portion represents the co-occurrences of identical grey levels in the adjacent pixel pairs To allow for some variations in digitization and detector response, we also included one off-center diagonal representing pixel pairs that differ by two. For each pixel, a comparison is made between that pixel and the previous pixel. If the pixels are equal, or differ by only two grey levels, that pixel is added to a histogram. The sum of all the diagonals of the co-occurrence matrix provides a more traditional histogram or grey-level distribution, as shown in the rotated co-occurrence matrix of Figs. 3 and 4. Fig. 5 shows the histogram found from the main diagonal of the co-occurrence matrix and the diagonal that represents pixel pairs that differ by two.

3.4 Threshold

Using the special histogram found from co-occurrences of identical pixel pairs and those that differ by 2, a target separation threshold can be calculated. The largest peak in the histogram is assumed to belong to the background and the target object temperature is assumed to be higher or lower than the background. A search is made of the histogram for the second highest peak that corresponds to the target or targets. To allow for noise in the histogram, the second peak must be a preset number of grey shade different from the background peak. The threshold is chosen to be the value at the local minimum between the target peak and the background peak Then the threshold is used to segment the image into candidate target areas (Fig 6). Some background pixels also will be on the same side of the threshold as the target, so features, such as target size, shape, and orientation, can be used to discriminate target from background. Time integration of detections also can be used to discriminate false detections and as the first stage in target tracking.

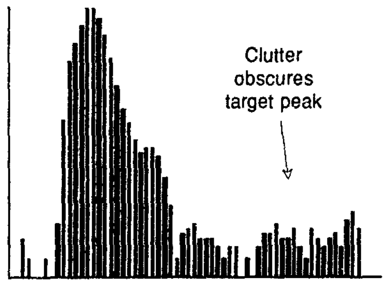

Fig 4 Regular histogram

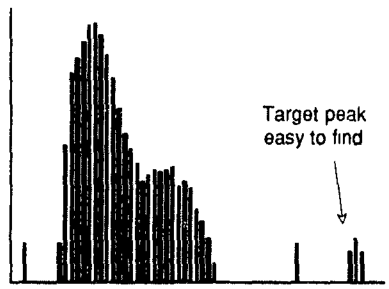

Fig 5. Co-occurrence histogram
(2 diagonals only)

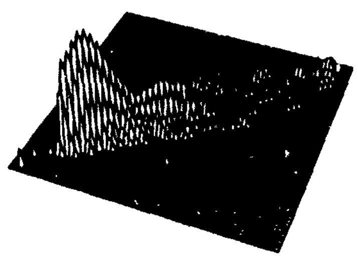

Fig 3. Rotated co-occurrence matrix

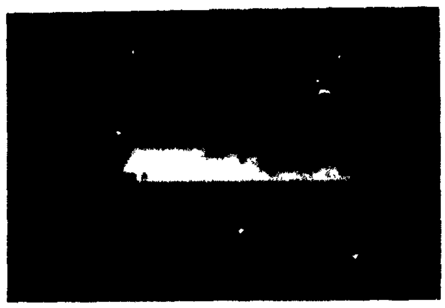

Fig 6. Segmented image

4. HARDWARE IMPLEMENTATION

We constructed our prototype processor on standard wire-wrap cards for ease of modifications and because of time constraints. The actual processor is shown in Fig. 7 Standard RS-170 video is fed into the processor, digitized, digitally processed, and reconverted to an analog video signal. The size of the processor can be greatly reduced in final packaging, but we were constrained to the size of the wire-wrap cards and the desire to partition the design by functions into separate modules.

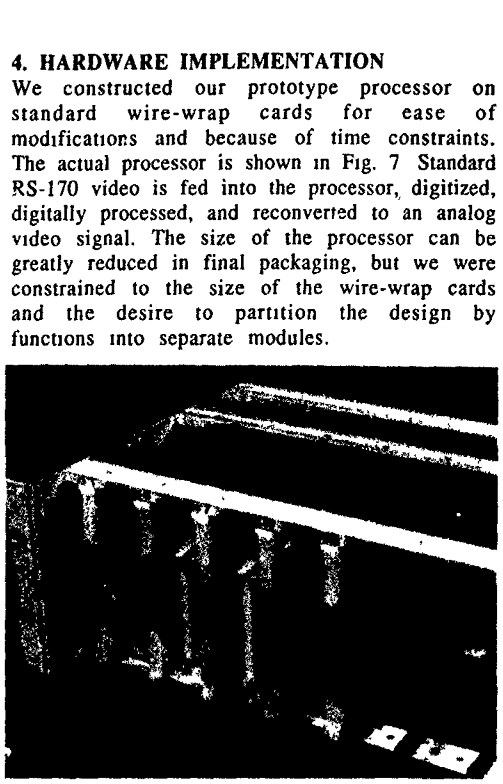

Fig 7. Processor hardware

4.1 Modularity

The processor to implement this design was made to take advantage of a modular design architecture (Fig. 8). The modular design allows for future expansion of the system or the use of the component modules in other image processing systems. The pixel information is processed serially as in standard video formats in a high-speed pipeline. No frame buffers or other memories are used to store the information in order to avoid delays and reduce system cost, weight, and power consumption. The design uses distributed power, and the only data shared between modules are a common master clock and a reset signal. The 8-bit pixel data are transferred asynchronously to a first-in first-out (FIFO) buffer on each module using a single bit to mark the end of lines and fields.

4.2 Digitization

One basic function necessary to process imagery digitally is to digitize the image. The incoming video signal (from IR imager or VCR) is digitized to 8 bits and 512 pixels per line. This resolution determines the pixel clock rate of 9.8 megahertz (MHz). The 9.8-MHz pixel rate is doubled to allow a faster system clock for processing. More precision in digitization is unnecessary in most applications. Digitizing is performed by a hybrid analog-to-digital (A/D) converter, Analog Devices AD9502, which will accept RS-170 video directly. Programmable logic devices (PLDs) 22V10 are used to convert the video sync information, supplied by the AD9502, to a special timing signal used to mark valid data, end of fields, and other information. Although a final configuration would use the signal directly from the focal-plane array and not RS-170, we used RS-170 because of its compatibility with many prototype IR arrays and standard video equipment.

4.3 Filtering

The IR imagery we used suffered from high-frequency system noise, which could easily be removed by median filtering. A small group of pixels is sorted by value and the middle value chosen to replace the center pixel. This process eliminates high frequency noise in an image and is often superior to averaging techniques. A nonlinear filter was implemented using an LSI Logic 64220 rank value filter (RVF). The RVF performs all the comparisons necessary to sort pixels in a configurable 64-pixel window at speeds up to 20 MHz. A simple 1-by-5 window was chosen for this application, and the median value chosen, although minimum or maximum filters also can be implemented. A simple state machine design implemented with standard 22V10 PLDs is necessary to initialize the RVF chip.

4.4 Co-Occurrence Histogram

The histogram of matching pixel pairs is computed by storing the current pixel in a latch and also storing that pixel with 2 added to it. Our circuit is shown in Fig. 9. The stored values are used in the comparison of neighboring pixels on a line. The function of adding two and latching is simple to implement with some logic equations and a standard 22V10 PLD. The stored values from the last pixel are compared to the current pixel If either pixel is the same, that pixel's grey level is added to the histogram. CMOS 8-bit comparators were used for the comparisons The histogram of co-occurrences is found using two

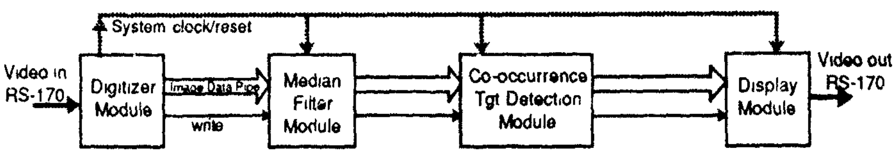

Fig 8 Modular architecture

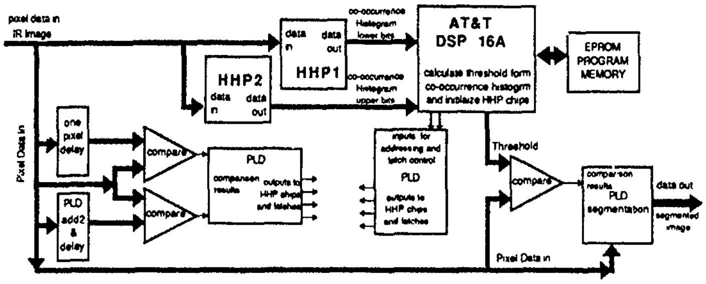

Fig 9. Hardware diagram

LSI Logic L64250 Histogram Hough Processor (HHP) chips. The HHP chip is equipped with accumulator RAMs to compute a histogram. Two chips are needed because the histogram values will exceed the 9-bit range of the HHP chips.

4.5 Threshold Calculation

The histogram is read out by an AT&T DSP16A digital signal processor (DSP) chip and segmented into target and background. A threshold for segmentation of the image is calculated and output to a latch. While co-occurrence histogram data take one frame to accumulate and additional time to process, the threshold used on the current pixel data is based on statistics from the previous frame. This technique avoids costly frame buffers and the associated delays. The fact that scene statistics don't change significantly from one frame to the next can be assumed.

4.6 Segmentation

The threshold stored in the latch is used by a 22V10 PLD and comparator to segment the image. Each incoming pixel is compared to the threshold and turned white if the pixel is on the target side. The pixels on the background side can be turned black or left alone, depending on how the imagery is to be used. Fig. 9 is a simplified diagram of how the co-occurrence histogram, target threshold, and target segmentation are implemented in our processor.

4.7 Reconversion to Video

After processing the digitized image, reconversion to an analog video signal is necessary to display the image. This reconversion is made using Analog Devices AD9701 digital-to-analog (D/A) converter. This component will construct a video signal from the 8-bit digital pixel information and video timing signals. Several 22V10 PLDs and counters were used to generate the necessary video timing signals

5. OTHER OPTIONS

The detected target or targets in the image can be used to cue an operator to the target for further discrimination or attention. The detected object can be tracked as it and the sensor move The target can be identified or classified by additional algorithms. Target detection is a necessary step for these and many other functions commonly required in military, scientific, and commercial imaging systems. The military applications include pilot or driver aids and warnings, missile guidance, and surveillance. Scientific and commercial applications include data collection, process controls, parts inspection, and parts orientation. Medical applications include X-ray analysis, tumor detection, and many other uses.

6. RESULTS

Video data at real-time rates (30 frames/second) were fed into the boards. The output of the boards was imagery with a threshold applied to segment a target While this resultant image alone is not very useful for a human operator, the image demonstrates the correct calculation of the target grey level and a threshold to segment it from the background A major advantage of this system is the flexibility provided by having each function on a separate board or module. This modularity allows many configurations and combinations of algorithms to be tested on a variety of imagery. The architecture allows other functions, such as tracking or target identification, to be added to the filter and target detection modules. Significant savings can be realized in modifications and optional configurations This signal processor and target detection method is now ready for application to many systems.

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METHODES DE FUSION OPTRONIQUE D'IMAGES IR ET VISIBLE

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1. INTRODUCTION

L'interprétation d'images peut être grandement facilitée en considérant simultanément des images d'une même scène produites par des capteurs de types différents. Ainsi, une approche globale du problème de fusion optronique entre deux capteurs IR et visible est abordée dans cet article, avec trois niveaux d'association des données

La fusion des données peut ainsi être effectuée au niveau décisionnel (classe d'objets), à un niveau intermédiaire (objets élémentaires) et enfin au niveau du signal issu directement des capteurs. A chaque étape de fusion se pose le problème de la mise en correspondance des données IR et visible. Cette mise en correspondance doit être d'autant plus précise que le niveau des données à associer est proche du capteur Cette phase préliminaire du traitement conditionne fortement l'étape de fusion. Les règles de fusion sont développées de façon à améliorer le pouvoir de classification, augmenter la probabilité de détection, utiliser la complémentarité éventuelle des capteurs, permettre une visualisation simultanée des informations pertinentes IR et visible à l'opérateur.

1.1. Fusion de données, fusion optronique

La fusion d'informations issues de senseurs différents présente les principales caractéristiques suivantes ·

- l'accroîssement spatial et temporel du volume de surveillance dû à la multiplicité des senseurs,
- l'amélioraton des performances, notamment par la réduction des durées d'initialisation,
- l'amélioration de la probabilité de détection

Dans le cadre de l'optronique, on s'adresse à un signal de type image L'optronique permet d'utiliser les bandes spectrales les plus favorables a la détection (observation nocturne (1), réduction de l'efficacité des camouflages) Elle autorise l'interactivité entre l'équipement d'observation et les interprètes de l'information reçue Ainsi le rôle de l'opérationnel, à partir de ces signaux, va être de détecter, de classifier, de reconnaître

La fusion d'informations peut alors s'opérer a differents niveaux plus ou moins élaborés du signal Il est évident que selon le niveau de fusion auquel on se situe, la nature des données à prendre en compte ainsi que les techniques de fusion à mettre en œuvre vont différer On peut alors évoquer le terme de hiérarchie dans l'approche de la fusion tant au niveau des données qu'au niveau des algorithmes

La figure 1 1 illustre sommairement l'aspect hiérarchique de la fusion en général et optronique en particulier On distingue sur cette figure les différents niveaux de fusion suivants :

- SIGNAL/PIXEL données brutes, recalage précis, filtrage et mélange d'informations pertinentes.
- OBJETS ELEMENTAIRES ou ALARMES . après détection, traitement sur zones, notion de recouvrement spatial, continuité temporelle, mesure de confiance, théorie des possibilités
- PISTES ELEMENTAIRES association d'alarmes, prédiction spatio-temporelle (ex filtre de Kalman)
- PISTES : calcul de distances, corrélation de trajectoires, fonction de coût
- DONNEES SYMBOLIQUES . classification, reconnaissance

Dans ce schéma de fusion, la notion d'environnement intervient au niveau du choix des capteurs, mais également au niveau de la confiance à accorder aux cibles détectées dans un contexte donné L'information extérieure concerne tous renseignements permettant de contribuer à une meilleure évaluation

Les travaux se situent dans cette structure de fusion successivement au niveau des alarmes, au niveau du signal brut (pixel) dans l'objectif d'une reconnaissance visuelle et enfin symbolique en vue d'une classification automatique

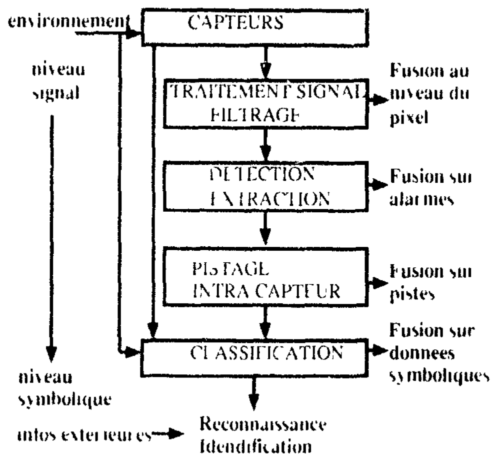


Fig. 1.1 - Fusion de capteurs à différents niveaux de représentations

2. ACQUISITION AUTOMATIQUE DE CIBLES

On utilise les bandes spectrales IR 8-12µm et visible 0.4-1/1µm dans le cadre de la fusion sur alarmes Les alarmes (cibles potentielles) sont issues des différentes voies de traitements d'un système de détection/poursuite opérant dans les bandes IR (2). Dans ce système les alarmes sont suivies temporellement (pistage) et une note (niveau de confiance) est attribuée à chaque piste. Les alarmes des pistes de meilleure note sont envoyées à un module de poursuite

2.1. Fusion sur alarmes entre IR 8-12µm et visible

Pour la vidéo thermique on opère par 3 voies de traitements :

- 1 voie destinée à la détection de cibles sur intensité (chaude ou froide),
- 1 voie destinée à la détection de cibles sur le mouvement,
- 1 voie destinée à la détection de cibles ponctuelles.

Dans le cas de l'imagerie visible sur fond de terre la notion de cible chaude ou froide n'a plus réellement de sens, c'est-à-dire que les voies liées au traitement par contraste ne sont plus adaptées. Cela a pour conséquence de réduire le pistage sur images visibles à la voie opérant par détection de mouvement.

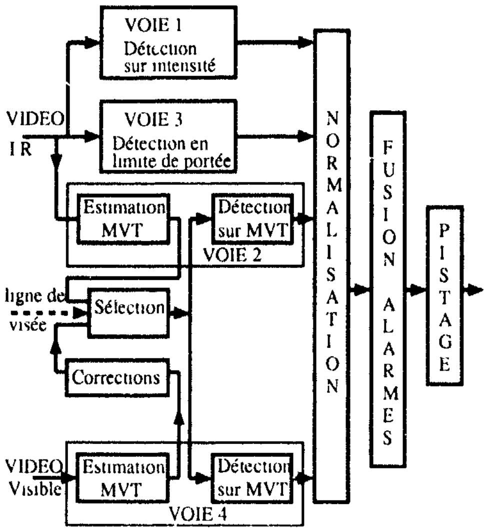


Fig. 2.1 - Pistage en bispectral

2.1.1. Relation entre les voies à détection de mouvement

Pour ces voies de traitements (2 et 4 en fig 2 1) les techniques retenues sont :

- recalage en trames homologues,
- estimation du déplacement par corrélation de phase,
- pondération du spectre de la corrélation

La méthode de recalage s'avère tres robuste Cependant, le contexte opérationnel amène à traiter des images bruitées et de très faible définition, qui font que l'estimateur de mouvement peut échouer dans l'estimation du vecteur correspondant au déplacement du fond

Lorsque l'on opère en bispectral, il est fort probable que l'une de ces bandes spectrales engendre une image de meilleure qualité que celle de l'autre bande.

Ainsi, lorsque l'on tente de recaler des images dans les deux bandes spectrales, il est sûr que le pic de corrélation le plus important en amplitude est issu des images les plus contrastées. Il s'avère également que d'une façon générale plus un pic de corrélation est important en amplitude plus la valeur du déplacement estimé est précise.

Ces diverses considérations ont permis d'élaborer une gestion des résultats des estimateurs de mouvement des images dans les deux bandes en procédant de la façon suivante :

a) calculer les coefficients de passage d'une bande spectrale à l'autre en ce qui concerne les vecteurs de mouvement,
b) valider les vecteurs estimés par une mesure sur le contraste en amplitude pour chacune des bandes spectrales,
c) sélectionner ou estimer un vecteur dans une bande par rapport à un vecteur valide dans l'autre bande,
d) à défaut s'appuyer sur l'information émanant de la ligne visée.

La détection sur le mouvement est réalisée entre une image de référence et l'image courante. En ce qui concerne le traitement bispectral, le changement de référence est synchrone (fonction de la valeur du déplacement).

D'autre part, les coefficients de passage d'un capteur à l'autre sont issus d'une opération de calibrage qui résout en partie les problèmes de mise en correspondance inhérents à l'utilisation simultanée de deux capteurs sur une même scène supposée plane, à savoir :

- la différence de position des capteurs,
- les différences de focales,
- les différences de grilles d'échantillonnage

Ainsi, le calibrage permet :

- d'assurer une bonne mise en correspondance des alarmes ou des pistes issues de sources différentes lors de la phase de fusion,
- de recaler "grossièrement" les images avant de fusionner au niveau du pixel tel que nous le verrons plus loin

2.2. Pistage

La fusion d'alarmes est élaborée avec un ensemble de paramètres de type spatial (taille, position dans l'image, centre de gravité, luminance moyenne)

Comparativement au pistage en monocapteur, on va manipuler des alarmes mixtes ayant des paramètres relatifs aux trois voies thermiques et à la voie visible.

Chaque voie de traitement est affectée d'un poids au sens de la théorie des possibilités qui rend compte de la crédibilité que l'on peut accorder à la voie en question

A titre d'exemple, les alarmes des voies à détection de mouvement sont retenues en fonction :

- du nombre d'alarmes,
- de la taille de l'alarme,
- de l'écart entre le vecteur de recalage estimé et l'information de la ligne de visée

2.2.1. *Fusion sur alarmes*

Fusion alarme-alarme

- Critère d'association

En imagerie IR on associait entre elles soit des alarmes chaudes soit des alarmes froides. Comme on est en présence de deux capteurs différents il faut donc considérer des associations mixtes A partir des observations faites sur les images IR et visibles les associations possibles qui ont été retenues sont présentées en table 2.1.

ALARME \ ALARME		IR C	IR F	VSB C	VSB F
IR	C	1	0	0	1
	F	0	1	1	0
VSB	C	0	1	1	0
	F	1	0	0	1

Table 2.1 - Association alarme-alarme

Ce critère est valable en intra et en inter-voie La notion de cible chaude ou froide s'exprime par

- moy2 ≤ 128 → cible froide (F)
- moy2 > 128 → cible chaude (C)

où ·

moy2 est la valeur moyenne de l'alarme calculée dans l'image délignée telle que

$$moy2 \quad \sum_{j,k \in alarme} (cour\,(j,k) - ECour\,(k) + 128)$$

avec

- Cour (j,k) correspondant à la valeur de luminance du point (j,k) de l'image courante
- ECour (k) étant la valeur moyenne de la ligne k de l'image courante

2.2.2. *Fusion alarme-piste*

Critère d'association

En 3 voies thermiques, une piste pouvait être rafraîchie simplement par une alarme chaude ou froide Dans notre cas de 4 voies une piste ou une alarme peut être issue de ·

- alarme IR chaude ou froide,
- alarme visible chaude ou froide,
- d'alarmes visibles froides et IR chaudes,
- d'alarmes visibles chaudes et IR froides

De fait les combinaisons d'associations envisagées sont données par la table d'association 2 2

PISTE / ALARME	VSB 0 / IR C	VSB 0 / IR F	VSB C / IR 0	VSB F / IR 0	VSB F / IR C	VSB C / IR F
VSB 0 / IR C	1	—	—	1	1	—
VSB 0 / IR F	—	1	1	—	—	1
VSB 0 / IR F	—	1	1	—	—	1
VSB 0 / IR C	1	—	—	1	1	—
VSB F / IR C	1	—	—	1	1	—
VSB C / IR F	—	1	1	—	—	1

Table 2.2 - Association piste-alarme

Une illustration de pistage en monocapteurs et bispectral est présentée par les photographies 1 et 2.

3. CLASSIFICATION DE CIBLES

3.1. Classification visuelle bispectrale

On aborde dans ce paragraphe, le problème de la fusion d'images au niveau du pixel Cette opération sous-entend d'une part la mise en correspondance des images de façon la plus précise possible, et d'autre part, la fusion proprement dite de l'information image.

La mise en correspondance des images à fusionner est réalisée en deux étapes ·

- la première effectue une correction grossière avec des paramètres approximés tel que cela est fait pour la fusion sur alarmes,
- la deuxième fait ce qu'on va appeler le recalage fin, qui consiste à mettre au mieux en correspondance les pixels, par l'intermédiaire d'un corrélateur de phase opérant par blocs d'images.

La fusion au niveau du pixel est traitée successivement par les deux méthodes suivantes :

- par pseudo couleur, où l'image visible est enrichie par l'apport de l'information IR dans le canal rouge d'une image construite en RVB.
- par technique pyramidale à partir du signal image.

3.1.1. *Mise en correspondance des images*

Le prérecalage effectué dans un premier temps donne entière satisfaction pour fusionner des alarmes mais est apparu insuffisant pour travailler au niveau du pixel

Bien que l'on désire travailler au niveau du pixel, il est indispensable d'utiliser les structures environnantes des pixels pour opérer la mise en correspondance Il convient de choisir une méthode de recalage robuste qui se présente de la façon suivante :

- découpage des trames par blocs homologues de 64 points par 32 lignes,
- corrélateur de phase en pleine définition.

Du fait que l'on traite des images de capteurs différents, l'utilisation des vecteurs est conditionnée à :

- un contraste d'amplitude entre le vecteur principal et les 4 pics de corrélation immédiatement inférieurs,
- un filtrage spatial et temporel glissant des vecteurs d'un bloc considéré.

Le principe est illustré par la fig. 3.1.

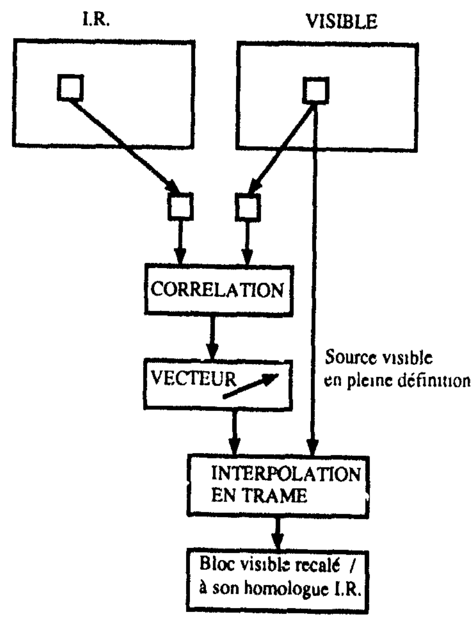


Fig. 3.1 - Reconstruction de l'image visible par rapport à l'image IR

3.1.2. Fusion par pseudo couleur

Une fois les deux images mises en correspondance une image de type RVB est construite. L'idée (3) consiste à renseigner l'image de la scène par les zones chaudes de l'image infrarouge, bien entendu sans la moindre opération de segmentation

De fait, les canaux V et B sont alimentés par l'image issue du capteur opérant dans le visible, tandis que le canal R contient l image IR 8-12μm. Dans la mesure où l'on travaille avec des images codées en Y DR DB, il est nécessaire de faire un transcodage Soient Rir la composante infrarouge et Vv, Bv les composantes du visible, les nouvelles valeurs Y, DR, DB (cf. fig. 3.2) sont calculées selon la référence (4) de la manière suivante ·

$$Y = 0{,}299.Rir + 0{,}587.Vv + 0{,}114.Bv$$
$$DR = 0{,}627.(Rir-Y) + 128.5$$
$$DR = 0{,}627\,(Bv-Y) + 128.5$$

Une illustration est présentée par les photographies 3, 4 et 5

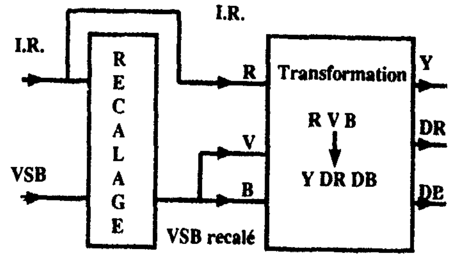


Fig. 3.2 - Fusion par pseudo-couleur

3.1.3. Fusion pyramidale

Le principe envisagé est très différent du précédent puisqu'on part de niveaux de gris pour arriver à des niveaux de gris, où l'objectif est d'intégrer dans une seule image les structures contenues dans les deux images candidates.

L'approche pyramidale de la fusion au niveau du pixel est principalement introduite dans les articles de références (5), (6) et (7). Cette méthode utilise un schéma de fusion hiérarchique des images basé sur une structure pyramidale de filtrage de type laplacien, laquelle a été développée initialement par Burt PJ et Adelson EH (8), (9) dans le but de la compression d'images. Cette décomposition s'appuie sur les différences locales de luminance

L'algorithme mis en oeuvre décompose dans un premier temps les deux images en différents niveaux de résolution tant en gradients qu'en valeurs moyennes dans un deuxième temps, à chaque niveau de résolution sont comparés les gradients relatifs. L'image de fusion est alors façonnée, en partant de la plus basse résolution, en privilégiant les zone de contraste les plus élevées ; ce qui permet de sélectionner les principales structures.

- <u>Construction de la pyramide de contraste</u>

La construction pyramidale au niveau des gradients est similaire à ce qui se fait en pyramide Laplacienne (9) Dans un premier temps la pyramide Gaussienne, ou de type passe-bas, est construite. Cette pyramide contient alors des images où chacune d'entre elles, est issue de la précédente après un filtrage passe-bas et un sous-échantillonnage un point sur deux dans les deux directions,

On désigne par G_0 le bas de la pyramide qui correspond à l'image originale Chaque étage de la structure est noté par l'indice l ($1 \le l \le N$ avec N l'indice du sommet de la pyramide) L'opération de filtrage et de sous-échantillonnage va être appelée REDUC , ainsi pour $1 \le l \le N$ nous avons ·

$$G_l = REDUC\,(G_{l-1})$$

avec

$$G_l(i,j) = \sum_{m=-2}^{+2} \sum_{n=-2}^{+2} f(n,m)\, G_{l-1}\,(2i+m,\, 2j+n)$$

Le filtre de taille 5*5 f(m,n) est séparable c'est-à-dire

$$f(m,n) = f'(m)\, f'(n)$$

avec (9) :

$f(0) = a$
$f(1) = f(-1) = 1/4$
$f(2) = f(-2) = 1/4 - a/2$

Du fait de la recherche des structures contenues dans les images à fusionner, une structure pyramidale de contraste va maintenant être réalisée. Pour un étage de la pyramide donné, le principe consiste à calculer le rapport entre le contraste local et la valeur moyenne locale.

La première étape est l'inverse de la précédente, en ce sens qu'on va réaliser une interpolation définie par l'opération EXPAND. La notation devient maintenant, $G_{l,k}$ l'image obtenue à partir de G en lui appliquant k fois la fonction EXPAND d'où :

$$G_{l,0} = G_l$$
$$G_{l,k} = \text{EXPAND}\,(G_{l,k-1})$$

avec

$$G_{l,k}(i,j) = 4 \cdot \sum_{m,n=-2}^{+2} f(n,m)\, G_{l,k-1}\left((i+m)/2, (j+n)/2\right)$$

où seulement les coordonnées entières de $((i+m)/2, (j+n)/2)$ contribuent au calcul de $G_{l,k}(i,j)$.

Par conséquent, on peut définir :

$$L_i = G_i - \text{EXPAND}\,(G_{i+1}) \text{ avec } 0 \le i \le N-1$$

$$L_n = G_n$$

Ainsi, chaque étage de la pyramide sous cette forme différentielle (L_i), devient équivalent à une opération de filtrage passe-bande à caractère laplacien. La pyramide en partant du bas est une représentation complète de l'image originale G_0 qui peut être retrouvée par reconstruction inverse sous la forme suivante :

$$G_n = L_n$$

et

$$G_i = L_i + \text{EXPAND}\,(G_{i+1}) \text{ avec } 0 \le i \le N-1$$

Il s'agit d'une reconstruction fondée sur une approche de type différentielle, en réalité on va opérer plutôt par le biais du rapport des gradients (au sens large) et de la luminance moyenne locale.

- *Fusion visible infrarouge*

Le schéma de fusion se résume à faire la décomposition pyramidale des deux images puis au moment de la reconstruction, à sélectionner le rapport de contraste les plus élevés pour un pixel situé à un étage donné et cela jusqu'à la pleine définition.

Le critère de sélection du gradient tient compte notamment de la luminance locale en IR (aspect détection).

On choisit une décomposition pyramidale à 5 niveaux, soit en partant de la pleine définition 4 niveaux de réduction (N=4) de définition.

Le principe général de fusion est illustré en fig. 3.3 où :

- les deux images A et B sont supposées recalées,
- les différents niveaux de résolution du point de vue des gradients sont notés par RA3, RA2, RA1 et RA0,
- la première sous-image (IF4) qui permet d'initialiser le processus de fusion est égale à la moyenne des sous-images GA4 et GB4.
- les image des gradients fusionnés sont notés par RF3, RF2, RF1, RF0

Enfin, en tenant compte des gradients et de la sous-image fusionnée interpolée on aboutit à l'image fusion de A et de B en pleine définition.

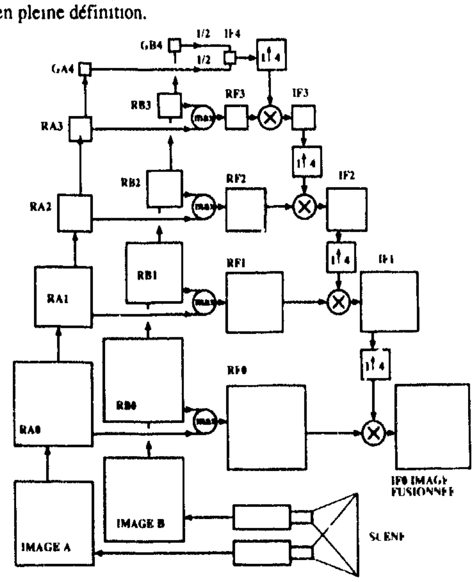


Fig. 3.3 - Représentation de la fusion d'images

Les photographies 6, 7 et 8 montrent une exemple de ce type de traitement.

3.2. Classification automatique

3.2.1. Classifieur neuronal

Les alarmes issues de la détection doivent être dans un premier temps classées en terme de cibles et fausses alarmes puis, les cibles sont reconnues selon leur catégorie, hélicoptères ou avion. La méthode de classification automatique mise en oeuvre dans notre application est fondée sur les techniques neuro mimétiques.

Ces techniques à base d'apprentissage sont bien adaptées pour résoudre le problème de classification de cibles à partir de l'image brute (i.e. sans prétraitement d'extraction des primitives caractéristiques des objets à classer). Ainsi, le réseau de neurones mis en oeuvre reçoit en entrée l'imagette 32x32 pixels codée sur 256 niveaux de gris représentant l'alarme à classer. En sortie, le réseau possède 4 neurones correspondant

à chaque classe (avion, hélicoptère, cible en limite de portée, et construction pour les fausses alarmes).

La description de la structure du réseau est donnée dans (10). Le réseau possède une couche d'entrée (e), une couche de sortie (s) et 2 couches cachées (fig. 3.4).

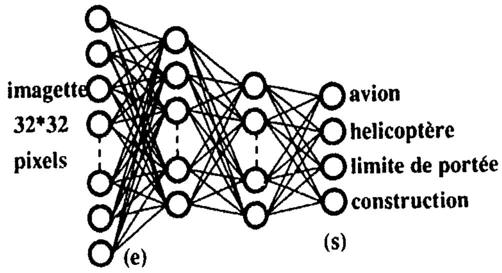
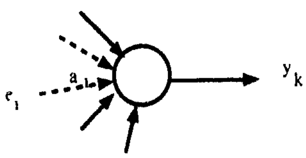


Fig. 3.4 - Réseau de classification

L'opération (fig 3 5) élémentaire effectuée au niveau d'un neurone est



$y_k = f(\Sigma\, a_i e_i)$

Fig. 3.5 - Opération élémentaire

où :

- e_i la ième entrée du neurone K correspond à la sortie d'un neurone de la couche précédente.
- a_i le ième poids synaptique associé à la liaison entre le neurone k et un neurone de la couche précédente
- f est une fonction seuil de type sigmoide de fig 3 6
- y_k la sortie du neurone k

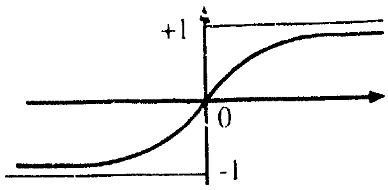


Fig. 3.6 - Fonction seuil

La phase d'apprentissage sur un grand nombre d'imagettes étiquetées (i.e de classe connue) permet d'obtenir le jeu de poids synaptiques tel que la sortie $y_s(1)$ soit proche de +1 pour les avions et $y_s(2)$, $y_s(3)$, $y_s(4)$ proches de -1, de même $y_s(2)$ proche de 1 pour les hélicoptères, etc

En phase de classification, une alarme inconnue va produire en sortie les valeurs $y_s(k)$ avec k = 1 à 4

Dans le cas monosenseur la décision consiste à choisir la classe C_i correspondant au neurone de sortie i où y_s est maximum

La méthode est appliquée aux deux bandes spectrales (IR et visible). Ainsi pour une même alarme vue par les 2 capteurs (IR et visible) les classifieurs neuronaux associés RN^{IR}, RN^{VSB} vont fournir les sorties y_s^{IR} et y_s^{VSB}. Le but de la fusion de ces réponses est d'obtenir une classification plus sûre que dans le cas monosenseur.

3.2.2. Fusion des classifications

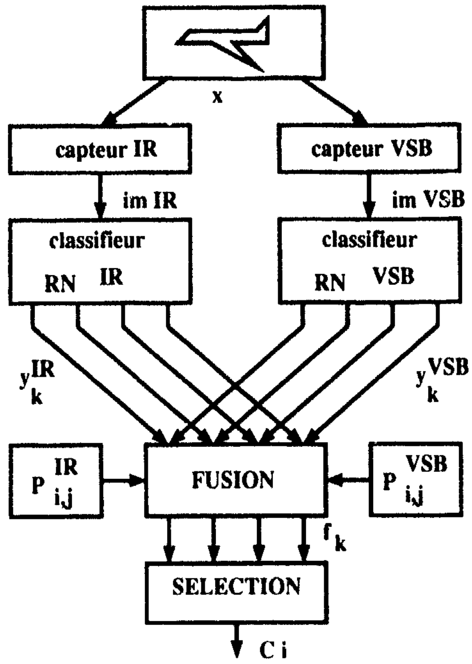


Fig. 3.7 - Synoptique de la fusion des classifications

L'algorithme de fusion suit le schéma illustré en fig. 3 7

- Soit im^{IR} (respectivement im^{VSB}) l'image de l'alarme x à classer vue par le capteur infrarouge (resp. visible).
- L'imagette infrarouge im^{IR} (resp. visible im^{VSB}) est présentée au classifieur infrarouge RN^{IR} (resp. visible RN^{VSB}) qui fournit en sortie y_k^{IR} avec k=1 à n (resp. y_k^{VSB}) qui après normalisation, peut être assimilée à la probabilité d'appartenance de x à la classe k selon le classifieur infrarouge (resp visible)
- D'autre part, le test des classifieurs sur une base élargie d'exemples a permis d'élaborer les matrices de confusion de chacun d'eux

Soit $P_{i,j}^{IR}$ (resp. $P_{i,j}^{VSB}$) la matrice de confusion du classifieur infrarouge (resp visible)

$P_{i,j}$ représente la probabilité pour un classifieur de choisir la classe j sachant que la cible présente est i.

$P_{i,j}$ représente la confiance que l'on prête à chaque décision du

classifieur et constitue la connaissance a priori qui est introduite dans le processus de fusion de la manière suivante :

Soit f_k k=1 à n le résultat de la fusion :

$$f_k = \frac{1-P^{IR}_{k,k} \;(1-Y^{IR}_k)}{1-P^{IR}_{k,k} \;\; Y^{IR}_k} \;\; \frac{1-P^{VSB}_{k,k} \;(1-Y^{VSB}_k)}{1-P^{VSB}_{k,k} \,.\, Y^{VSB}_k}$$

la sélection est alors effectuée selon :

x appartient à la classe C_i, avec i tel que $f_i = \max(f)$

4. CONCLUSION

Si l'on se réfère à l'architecture du système de détection/poursuite (2), en ce qui concerne les traitements de bas niveau (filtrages, recalages) et haut niveau (alarmes, pistes), il se trouve que la fusion au niveau des alarmes soit bien appropriée. En effet sur fond de terre, l'apport d'un capteur opérant dans le visible se traduit par l'adjonction d'une voie ;

Un des points importants de ce travail a été de relier les voies opérant par détection de mouvement au niveau des processus de recalage, en ce sens qu'un estimateur de mouvement dans une bande spectrale peut, en cas de déficience, s'appuyer sur les résultats de l'estimateur de l'autre bande. En dernier recours on fera appel à l'information émanant de la ligne de visée.

L'approche de fusion au niveau du pixel par pseudo couleur est du point de vue visuel d'un bon rapport performance/coût du fait de sa simplicité de mise en oeuvre.

La technique de fusion pyramidale présente le principal avantage de préserver les détails fins de chacune des images. Du fait que l'on travaille en sous-bandes (signal), il est tout à fait possible d'intervenir dans ces dernières, en introduisant des coefficients de pondération selon un certain critère. Autrement dit, on peut favoriser à souhait un capteur par rapport à un autre, en intervenant dans une ou plusieurs sous-bandes spectrales (signal). Dans le cadre de notre application, un des critères retenu peut opérer la fusion, a été de privilégier les zones de l'infrarouge.

Ce type de fusion demande un recalage quasi parfait, les résultats semblent montrer que les algorithmes mis en oeuvre permettent d'y arriver. Cependant certains effets inhérents aux capteurs tels que le trainage, la saturation et l'éblouissement des pixels voisins ne sont pas encore maîtrisés. Un des problèmes en suspens concerne la création d'artéfacts lors de la fusion de zone ayant de contours à contrastes inversés (ex : bords de toit de maison).

Les résultats sur séquences d'images sont prometteurs en ce sens qu'une telle technique de fusion d'informations peut être une aide à l'opérateur, mais il est bien évident que seul les opérationnels sont aptes à porter un tel jugement.

Pour ce qui est de la classification automatique par technique neuronale, un deuxième capteur apporte incontestablement une dimension supplémentaire au demeurant fort utile pour lever certaines ambiguités

Le point commun aux trois méthodes de fusion, dans le cadre de l'optronique, est la mise en correspondance des informations à fusionner qui se concrétise par un recalage. Il est bien évident que plus on remonte vers le capteur, plus on traite de l'information brute, et plus le recalage doit être précis.

En définitive quel que soit le mode de fusion utilisé, on peut affirmer qu'à des degrés divers, le multicapteur apporte vraiment un plus par rapport au monocapteur. Il reste cependant encore des travaux de développement à effectuer sur la fusion au niveau du pixel par la technique de filtrage par sous-bandes, ainsi que sur l'approche par fusion des classifications.

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Photo 1 -

Source IR	Source visible
Pistage IR	Pistage visible

Photo 2 - Source IR + Pistage (IR+visible) après fusion sur les alarmes

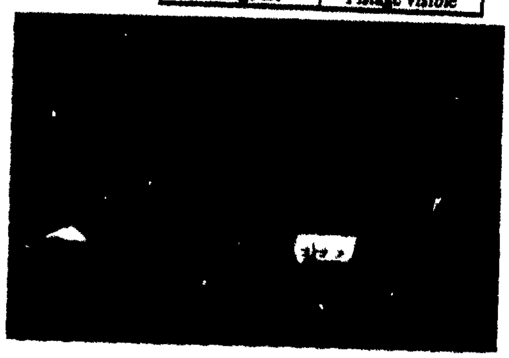

Photo 3 - Source IR

Photo 6 - Source IR

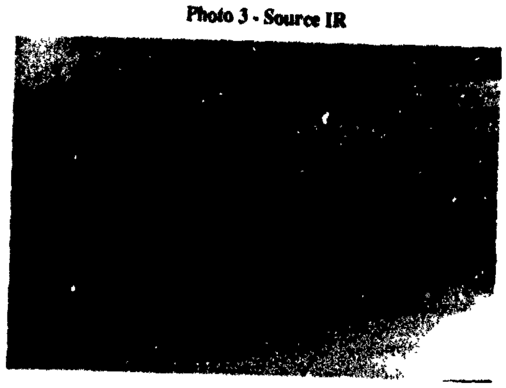

Photo 4 - Source visible

Photo 7 - Source visible

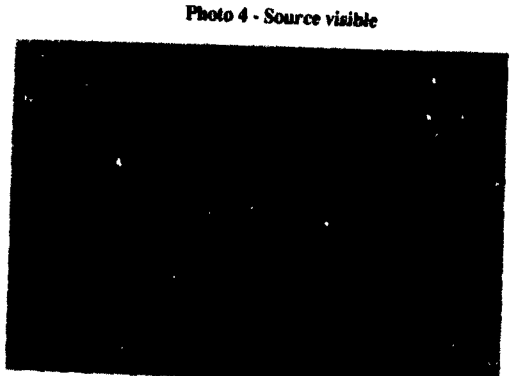

Photo 5 - Fusion pseudo-couleur

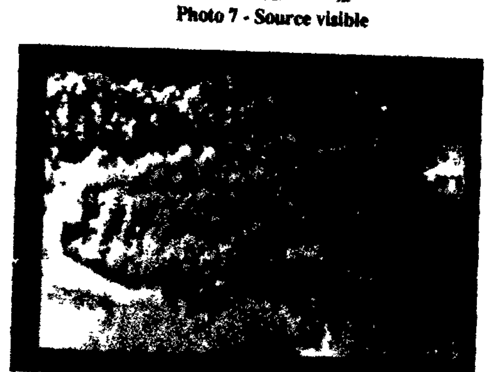

Photo 8 - Fusion pyramidale

DETECTION, POURSUITE ET CLASSIFICATION AUTOMATIQUES EN IMAGERIE INFRA-ROUGE

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1. INTRODUCTION

Cet article aborde certains aspects des techniques de traitement d'images et de reconnaissance des formes pour la détection, la poursuite et la classification automatiques de cibles en imagerie infra-rouge.
Les algorithmes décrits dans ce papier sont mis en oeuvre en temps réel pour des cibles avions, hélicoptères et missiles en vue de leur intégration dans un écartomètre d'un système de défense sol-air. Néanmoins, il sont suffisamment généraux pour être appliqués également aux équipements optroniques des systèmes d'armes air-sol et air-air.

Les traitements mis en oeuvre sont de deux catégories :

- Ceux qui portent sur tout le champ analysé par le senseur (typiquement 2° x 3° pour une caméra thermique d'un système d'armes courte portée). Ces traitements extraient du fond les cibles potentielles (appelées alarmes). Les critères de segmentation sont fondés sur le contraste et le mouvement des cibles par rapport au fond ;

- Ceux qui portent sur des zones réduites de l'image (fenêtre de poursuite) et qui ont pour but de classer (reconnaitre) les cibles potentielles et de poursuivre (localiser à chaque instant) les cibles reconnues.

On présente au paragraphe 2 les algorithmes de détection de cibles évoluant sur des fonds variés. Une technique de classification par Réseaux de Neurones est proposée au paragraphe 3. La conclusion décrit la mise en oeuvre de ces fonctions dans une maquette temps réel d'un écartomètre multicibles.

2. DETECTION D'ALARMES

Pour assurer la fonction d'extraction de cibles de nature différente (avions, hélicoptères, missiles) lointaines ou proches, évoluant sur des fonds uniformes ou texturés, les algorithmes mis en oeuvre utilisent les informations de contraste et de mouvement. Les traitements associés à l'information de contraste permettent de détecter des objets fixes ou mobiles présentant des caractéristiques en luminance différentes de celles du fond environnant (caractère plus chaud ou plus froid en IR).
Les traitements liés à l'analyse du mouvement viennent compléter les traitements précédents dans la mesure où ils permettent de détecter des objets mobiles faiblement contrastés.
Pour couvrir l'ensemble des situations envisagées trois algorithmes de détection (trois voies de traitement) sont utilisés.

2.1. Détection de cibles ponctuelles (voie 1)

En limite de portée (≈ 10 km) les cibles apparaissent comme des sources ponctuelles (quelques pixels) localement contrastées, animées d'un très faible mouvement apparent. Pour assurer une détection précoce (rapport signal à bruit faible) l'algorithme combine un traitement spatial et temporel.

a) Filtrage spatial

$g(x,y) = \left| \bar{f}nxn\,(x,y) - \bar{f}mxm\,(x,y) \right|$ avec $n < m$ et $\bar{f}nxn$ moyenne pondérée sur un voisinnage (nxn)
Les extrema locaux de l'image filtrée g (x,y) sont retenus comme alarmes potentielles.

b) filtrage temporel

Les alarmes potentielles sont confirmées par accumulation temporelle. Le traitement permet de conserver les extrema dûs aux cibles qui présentent un faible mouvement apparent et d'éliminer les extrema dûs aux pointes de bruit dont les positions dans l'image sont aléatoires en fonction du temps.

$$C^t(x,y)=\frac{1}{2}C^{t-1}(x,y)+2K^t(x,y)\Sigma\ \Sigma\ C^{t-1}(x\text{-}n,y\text{-}m)$$

où K^t est l'image des extrema à l'instant t et C^t (x,y) la valeur de l'accumulateur. Les pixels (x,y) connexes pour lesquels C^t (x,y) atteint un seuil T_1 sont regroupés en alarmes.

2.2. Détection de cibles larges (voie 2)

Cet algorithme de détection est bien adapté pour la détection de cibles contrastées et proches. Il est fondé sur une technique de seuillage adapté.
Le seuil est déterminé de la manière suivante :

soit f (x,y) l'image source redressée par rapport à sa moyenne globale M_G

$g(x,y) = |f(x,y) - \bar{f}_{3\text{-}3}(x,y)|$ l'image gradient.
Le seuil de détection T_2 est évalué au point xm, ym où la somme luminance + gradient est maximum et prend la valeur :
$T_2 = f(xm, ym) - \alpha\ g(xm, ym)$.
Les pixels (x,y) connexes pour lesquels f (x,y) > T_2 sont regroupés en alarmes.

2.3. Détection de mouvement (voie 3)

Sur les fonds terrestres, qui sont par nature texturés, les algorithmes de détection fondés uniquement sur le critère de contraste engendrent des fausses alarmes. Pour lever ces ambiguités, la segmentation cible/fond est effectuée sur un critère de mouvement. En effet, le paysage est animé d'un mouvement dû au déplacement de la caméra et les cibles se distinguent par un mouvement différent.
On procède en deux étapes : (photo 1)

a) Estimation du déplacement du fond

Le déplacement recherché est une translation pure et une méthode de corrélation de phase peut être utilisée :
soit f_1 (x,y), f_2 (x,y) = f_1 (x-dx, y-dy)
2 images successives et F_1 (u,v), F_2 (u,v)
leur transformées de Fourier respectives.

$$G\ (u,v) = \frac{F_2(u,v).\ F_1^*\ (u,v)}{|F_2\ (u,v)\ .\ F_1^*\ (u,v)|}$$ la matrice de corrélation de phase.

La transformée inverse de G (u,v) présente un pic situé en (xo, yo) correspondant au déplacement recherché (dx, dy).

b) Recalage et différence d'images recalées

Après recalage de l'image f_2 par (dx, dy) on effectue une différence inter-image
$diff\ (x,y) = |f_1(x,y) - f_{2\,rec}(x,y)|$
Les pixels (x,y) connexes tels que diff (x,y) > T_3 sont regroupés en alarmes.

2.4. Alarmes et attributs

En sortie de chacune des voies de traitement les alarmes détectées sont caractérisées par des attributs (position et taille de la fenêtre rectangulaire entourant au mieux l'alarme, surface en nombre de pixels, centre de gravité, intensité moyenne dans l'image source, numéro de la voie de traitement).
Les trois traitements fonctionnent en parallèle et n'ont pas un caractère exclusif. Ainsi une cible de taille moyenne en mouvement donnera lieu à une alarme sur la voie 2 (cible contrastée) et sur la voie 3 (détection de mouvement). De plus, ces alarmes dites homologues (i.e correspondant au même objet) peuvent donner lieu à des représentations différentes du même objet
L'exactitude de la représentation est liée à l'aptitude d'une voie de traitement à segmenter correctement l'objet dans un contexte donné (contenu de la scène observée). Le but de la fusion de données n'est pas de valider les alarmes en tant que cibles mais d'évaluer les attributs "réels" de la cible à partir des valeurs d'attributs mesurées sur les alarmes homologues et d'une mesure de la confiance que l'on peut accorder à chacun des traitements pour ce contexte.

3. CLASSIFICATION DE CIBLES

3.1 Intérêt de la classification

L'étape de détection précédente fournit des alarmes qui sont potentiellement des cibles dans la mesure où elles satisfont au critère de contraste (plus chaud ou plus froid que le fond) ou au critère de mobilité par rapport au mouvement du fond dû au déplacement du capteur.
Dans un environnement de type champ de bataille, de nombreux objets peuvent répondre à ces critères : (photo 2)

- les vraies cibles : avions, hélico, missiles,
- les fausses alarmes : leurres pyrotechniques, feux, toits et constructions, véhicules terrestres...

Ce nombre important de détections peut saturer les systèmes automatiques et ne peut être géré par un opérateur humain. La fonction de classification a pour but initial de lever ces

ambiguités en classant ces cibles potentielles en "cible" ou "fausse alarme".
Parmi les objets classés dans la catégorie "cible" la fonction classification permet de déterminer le type de la cible en terme d'avion, d'hélicoptère ou de missile.
Cette nouvelle information est utilisée pour donner une priorité à chaque cible et contribue à l'évaluation de la menace.

3.2. Classification par réseaux de neurones

La classification de cibles aériennes en imagerie Infra-rouge est un problème non trivial. En effet les signatures thermiques des objets à reconnaître sont très variées, bruitées et souvent représentent les cibles de manière incomplète. La modélisation de ces signatures est très délicate et l'application des techniques classiques de reconnaissance de forme ne donne pas de résultats satisfaisants. Par contre on peut constituer, au cours d'expérimentations, une base de données représentative des données à traiter en enregistrant un grand nombre de cibles dans des situations variées et d'objets susceptibles de donner des fausses alarmes. Cette base de données constitue alors un ensemble d'exemples étiquetés. Les méthodes fondées sur les réseaux de neurones sont, grâce à leur capacité d'apprentissage par l'exemple, bien adaptées pour résoudre le problème de classification.

- structure de réseau (1)

La méthode repose sur la mise en oeuvre d'un réseau de type "Perceptron Multi Couches". Ce réseau reçoit en entrée des sous-images de taille 32 x 32 pixels représentant l'objet à classer.
Ces sous-images correspondent aux zones extraites par les traitements de détection. Les sorties du réseau correspondent aux 4 classes : avions, hélicoptères, cible en limite de portée, construction. La structure choisie est une sturcture à quatre couches entièrement connectées (fig. 1).

- la couche d'entrée (E) de 1024 neurones correspond aux pixels de l'image (32 x 32) codés sur 8 bits,
- 2 couches intermédiaires, (I) de 100 neurones et (J) de 30 neurones, appelées couches cachées
- 1 couche de sortie (S) comp[illegible] les 4 neurones associés aux 4 classes possibles dans la version actuelle.

- Apprentissage

En phase d'apprentissage 4000 imagettes étiquetées (exemples) ont été présentées au réseau. Une méthode d'apprentissage non-supervisé de type KOHONEN permet l'auto organisation des données en nuages, puis la méthode de Rétropropagation du gradient est appliquée pour obtenir les poids symaptiques utilisés lors de la phase de généralisation.

- Généralisation

Les performances obtenues en généralisation sur un ensemble test (i.e contenant des images non apprises par le réseau) sont de l'ordre de 95 % de bonne classification entre cibles et fausses alarmes et de 85 % de bonne discrimination entre cible "avion" et cible "hélicoptère".

4. CONCLUSION

Sur la base de ces algorithmes de détection la maquette temps réel d'un écartomètre numérique multicibles (ENM) a été développée. La fonction de cet équipement, couplé à une caméra IR ou TV, est d'assurer la détection des cibles et le guidage d'un missile jusqu'à l'interception. Cette maquette exploratoire est actuellement en test sur site, interfacée à un système d'arme courte portée CROTALE.
L'ENM se compose de 3 modules principaux (figure 2).
Le premier module assure la détection multi-algorithmes et le pistage dans tout le champ analysé de 20 objets susceptibles d'être une cible.
Le deuxième module assure la poursuite rapide de 4 objets sélectionnés. Dans notre application ces 4 objets seront 2 cibles et 2 missiles tirés pour intercepter ces cibles.
La fonction classification est directement liée au troisième module, qui est un module de supervision. Elle permet de limiter les fausses alarmes et participe à la sélection des cibles prioritaires à passer au module de poursuite rapide.

Dans sa configuration actuelle la maquette travaille dans une seule bande spectrale. Le traitement multi-algorithmes est appliqué soit à la vidéo infrarouge soit à la vidéo visible.
Des études complémentaires (2) sont actuellement menées et visent à mettre au point une technique de fusion multi spectrale de manière à utiliser au mieux la complémentarité des bandes spectrales infra-rouge et visible pour améliorer la fonction détection.

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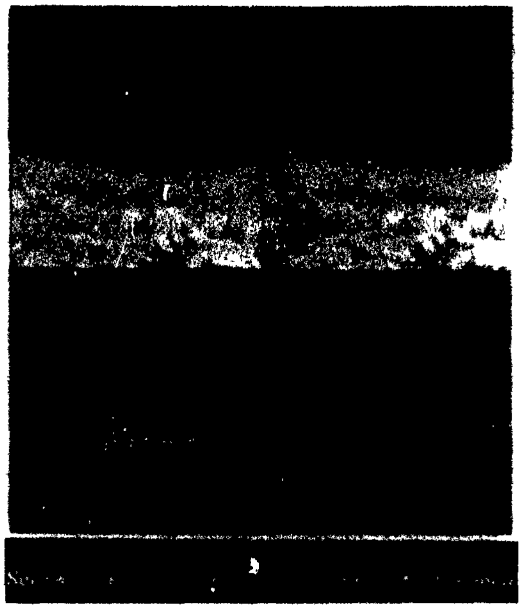
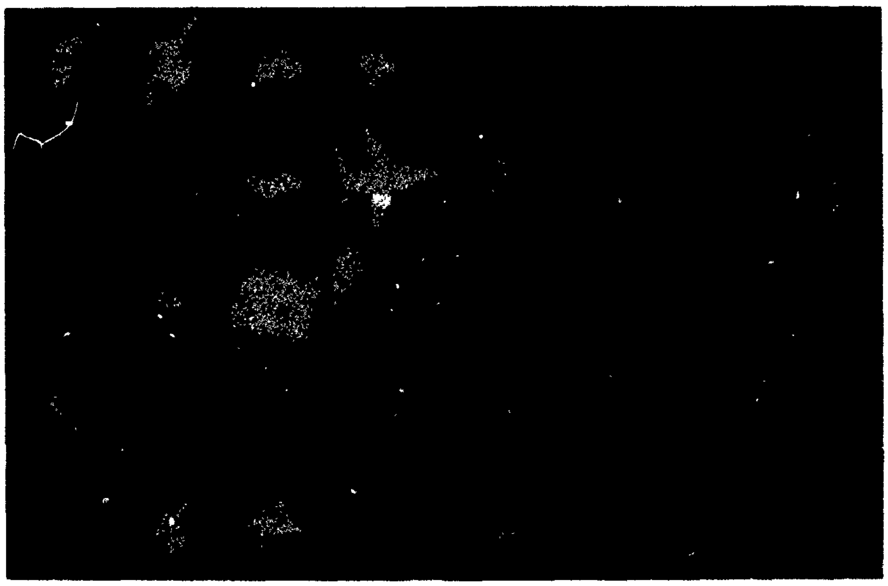
D. Thoreau (LER), J. Quignon TH-CSF.

Détection de cibles mobiles par corrélation de phase.
Photo 1



Imagettes des alarmes à classer
Photo 2



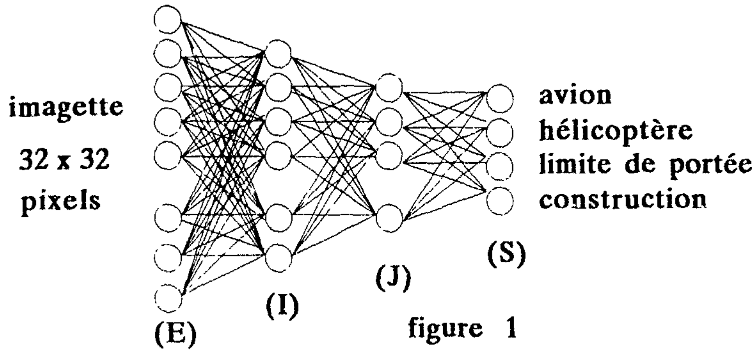


figure 1

Structure du réseau

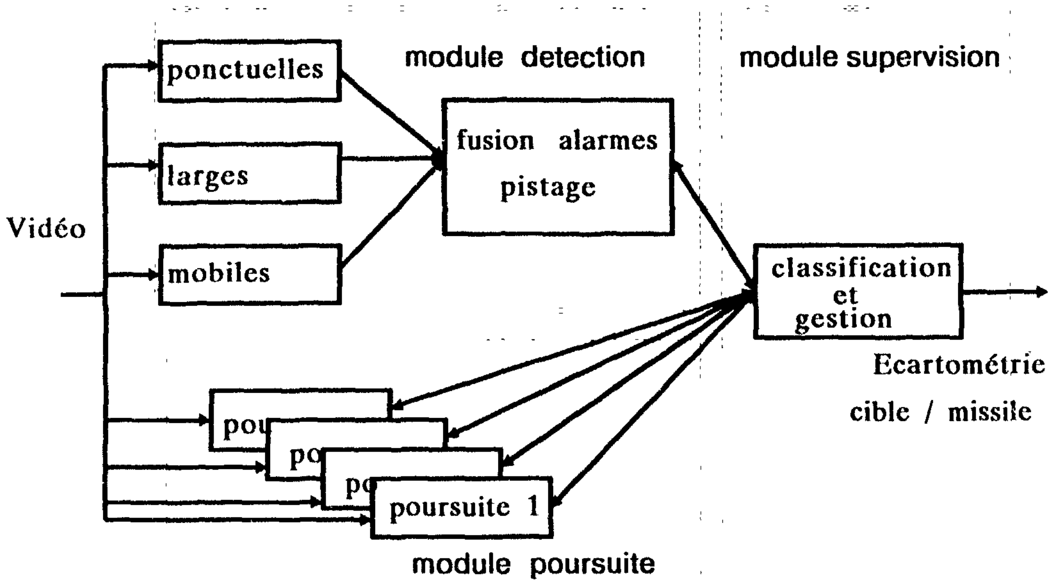
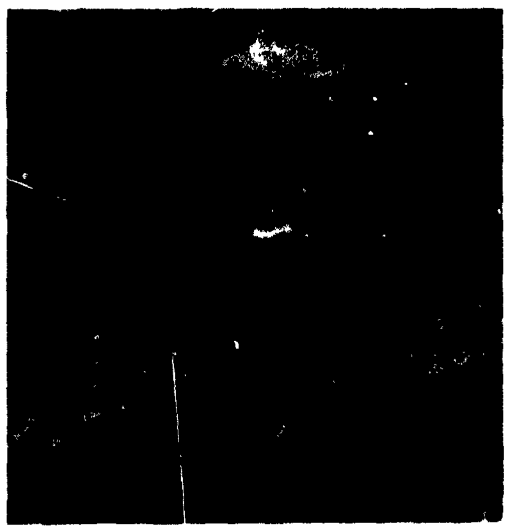


figure 2

Ecartomètre Numérique Multicibles

Exemple de scène I.R



_ detection et pistage :

1 hélicoptère PUMA (au centre)

1 camion en mouvement (à gauche)

4 cibles potentielles (à droite)

DISCUSSION

DISCUSSOR : **Mr H.W. PONGRATZ** (Germany)
(NU). Does the Neural Network use directly the pixel data or is there an upfront feature extraction before the trainable network ?

AUTHOR'S REPLY :
(NU). Yes, the training phase is performed using the raw data, that is the grey value of the pixels of the image.

INFRARED TARGETING SYSTEM (IRTS) DEMONSTRATION

October 1991

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1. SUMMARY

The Infrared Targeting System (IRTS) is a technology demonstration program sponsored by the Avionics Directorate, Wright Laboratory, Wright Patterson AFB, OH. The prime contractor for this three year effort is Boeing Military Airplanes, Wichita, Kansas. The objective of the IRTS program is to successfully demonstrate the mission performance that can be achieved in manned air-to-ground targeting applications utilizing a synergistic combination of state-of-the-art active/passive infrared sensor and automatic target recognizer (ATR) technologies. The IRTS program is centered around a demonstration FLIR/Laser Radar/ATR (FLASER). The FLASER consist of a dual field-of-view (2x2 degree and 6x6 degree) second generaton FLIR pixel mapped to a CO2 laser radar, with a FLIR ATR processor, a laser radar ATR processor, and a sensor fusion ATR processor. In addition to the FLASER, other elements of the IRTS equipment configuration include a digital terrain data base, FLIR tracker, ATRWG (Automatic Target Recognition Working Group) standard recording equipment, and a central control console. Following construction and laboratory testing of the IRTS, the system will be installed on a test aircraft and demonstrated in flight against realistic Tactical, Strategic, and Special Operations scenarios.

2. INTRODUCTION

The Infrared Targeting System (IRTS) is a technology demonstration effort sponsored by the Avionics Directorate, Wright Laboratory (WL), Wright Patterson AFB, OH. The prime contractor for this effort is Boeing Military Airplanes, Wichita, Kansas. The objective of the IRTS program is to successfully demonstrate the mission performance improvements over current EO targeting systems by utilizing a synergistic combination of state-of-the-art (SOTA) active/passive infrared sensor and automatic target recognizer (ATR)

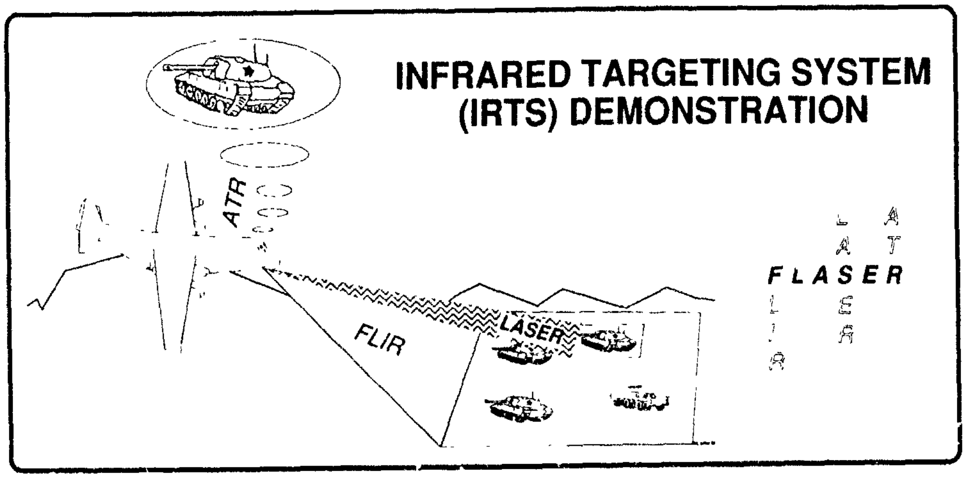


Figure 1. Infrared Targeting System (IRTS) Demonstration

technologies in an air-to-ground manned platform scenario.

The long term goals are to develop a FLASER sensor for detecting, classifying, and recognizing tactical and strategical mobil targets. FLASER (FLIR/Laser Radar/ATR) as applied to IRTS is depicted in Figure 1. Future FLASER sensors could be comprised of an integrated electro optic (EO) sensor consisting of a multifunctional, multiphenomenology laser sensor, a multispectral passive imaging system, and automatic target cueing/recognition systems.

The IRTS sensor suite will consist of a dual field-of-view (nominally 2x2 degree and 6x6 degree) second generation 8 to 12 micron band FLIR ground mapped to an advanced multi-function CO2 laser radar. Processors include a FLIR ATR processor, a laser radar ATR processor, and a sensor fusion ATR processor. Other elements of the IRTS demonstration configuration include a digital terrain data base, FLIR tracker, ATRWG (ATR Working Group) standard recording equipment, and a central control console.

During the proposed IRTS flight demonstration, extensive ground truth collection is required along with the sensor imagery. The ground truth information is necessary to support data analysis to establish system performance as a function of test conditions. Lessons learned in critical areas could mitigate risk in future sensor programs.

2.0 TECHNICAL APPROACH

2.1 OVERALL ARCHITECTURE

Figure 2 shows a conceptual block diagram of the IRTS demonstration sensor. It consists of the advanced FLIR and laser radar, their respective ATRs, the fusion ATR, and a FLIR tracker and electronics. In order to facilitate ground mapping, i.e., the mapping (not necessary one-to-one) from the FLIR narrow field-of-view (NFOV) pixel coordinates to the corresponding laser radar pixel coordinates, the laser radar and FLIR must have, as a minimum, a common aperture. Figure 2 shows one of the possible ways to achieve the pixel mapping; use of a dichroic and a common pointing mirror.

One of the major characteristics of the IRTS laser radar is the fast random access mode which allows the laser radar scanner to point rapidly to any point within the FLIR NFOV and perform raster scans of dynamically selectable sizes. This capability allows the laser radar to interrogate different targets or take multiple frames of data from the same target.

The purpose of the operator, depicted in the 'OPERATOR CONSOLE' from Figure 2, is to aid in area-of-interest (AOI) selection and to monitor the operation of the system during the demonstration/data gathering flights.

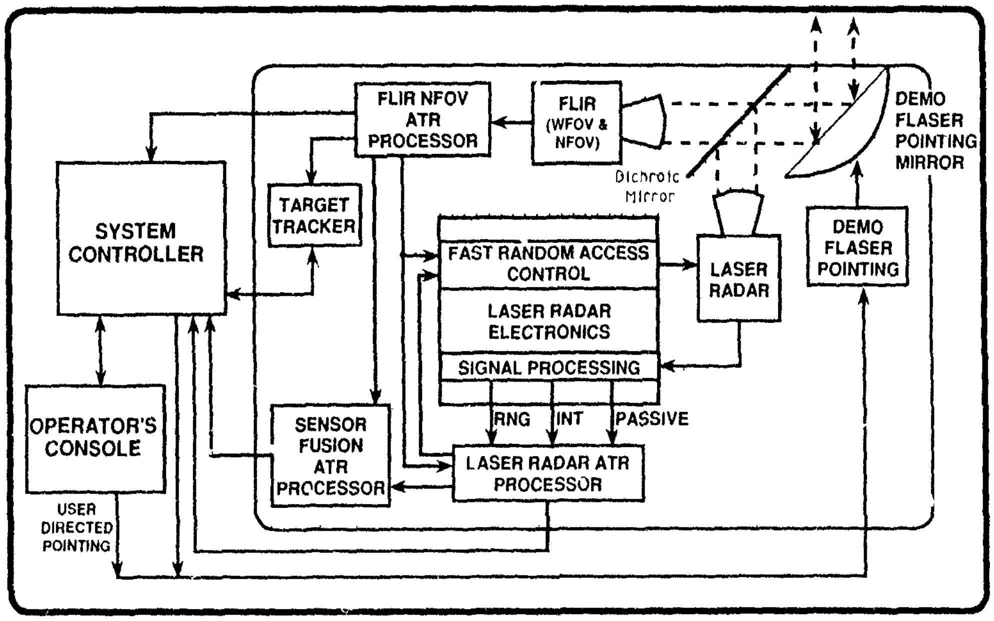


Figure 2. IRTS Demonstration Sensor

A more detailed, high level IRTS system architecture has been defined and is shown in Figure 3. It shows all the major components, including the sensor and ATR subsystems, and their interconnects. A C-130 is invisioned as the airborne platform for the program. The aircraft turret is depicted in the figure for providing the housing for the sensor subsystem.

2.2 Sensor Subsystems

The IRTS sensor subsystem consists of a boresighted FLIR and laser radar. Initial systems engineering studies showed that the FLIR/Laser Radar assembly should be boresighted so that the ground position of the laser radar pixel information would be known to within one FLIR pixel ("ground registered"). This requirement allows features detected by the FLIR ATR to be matched spatially with features identified by the laser radar ATR.

The FLIR will have a wide and narrow FOV mode, with the WFOV mode 3 times that of the NFOV mode. The FLIR will be an advanced second generation sensor, i.e., digital DC coupled output with a minimum 10 bits resolution, non-interlaced, with 2 samples per IFOV (Instantaneous field of view) in horizontal and vertical directions. The laser radar will have a fast random access scan (at least 10 targets of 3m x 5m size, per second), small beam size (<= 0.1mrad), and a passive channel (not to be confused with the FLIR). The purpose of the passive channel is to provide truly "pixel mapped" (vs. "ground mapped") data for laboratory analysis and research. See Figure 4 for a block diagram of the sensor subsystem.

2.3 ATR Subsystem

The ATR subsystem consists of a FLIR NFOV mode ATR, a laser radar ATR, and a sensor fusion ATR. Figure 2 depicted a block labeled 'OPERATOR's CONSOLE'. The operator's input into the IRTS system is to act as the primary detector and classifier for areas-of-interests (AOIs). In a cost reduction effort, it was decided to insert a human operator into the system to locate AOIs. These AOIs are then passed to the FLIR NFOV mode ATR for evaluation.

The FLIR NFOV mode ATR acquires FLIR NFOV mode sensor data at 30 frames per second, detects and classifies objects-of-interrests (OOI), with confidence value, and provides prioritized lists of objects to the laser radar and sensor fusion ATRs. The NFOV ATR performs detection and classification with as few as 100 pixels on target.

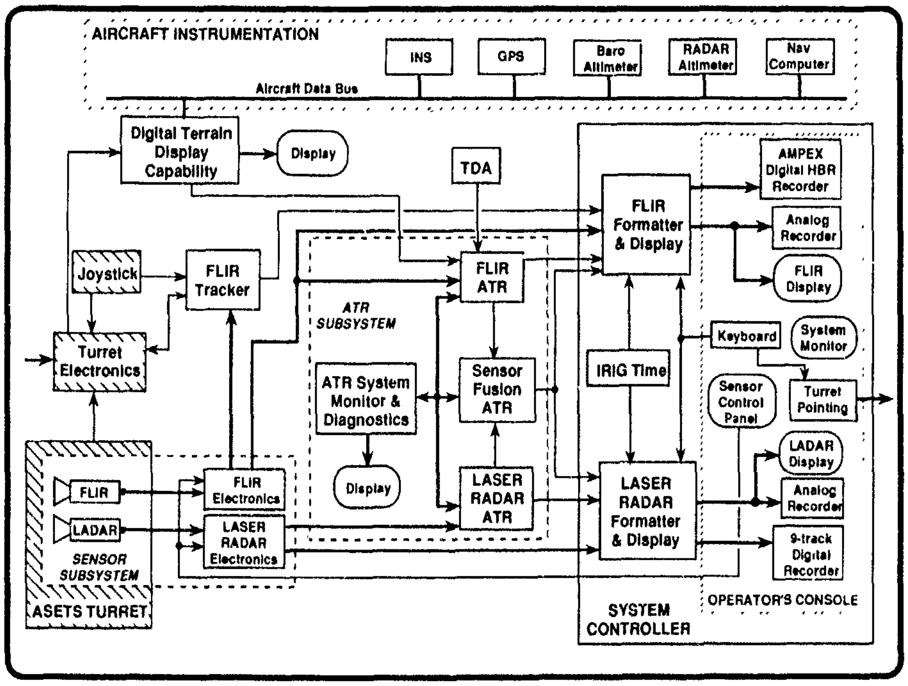


Figure 3. IRTS System Architecture

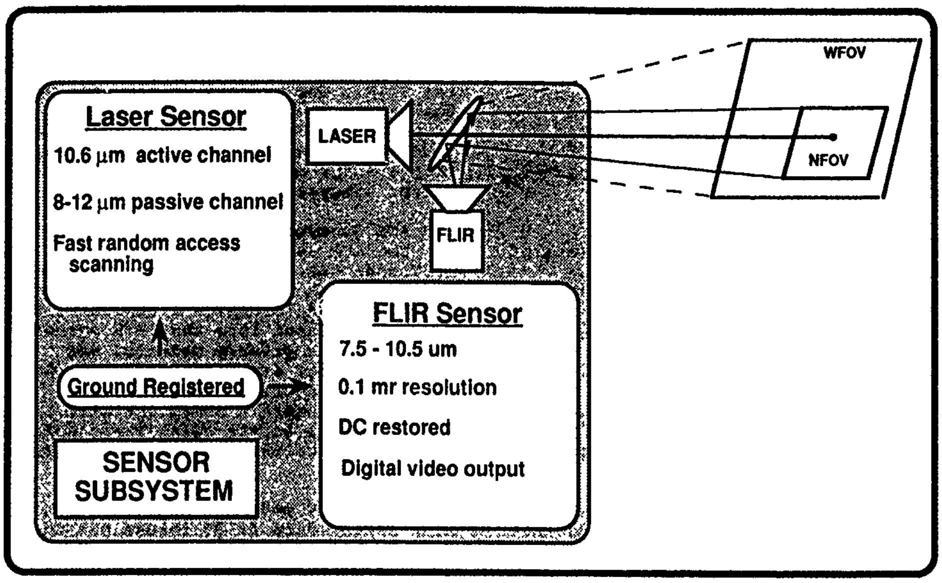


Figure 4. Concept for Sensor Subsystem

The laser radar ATR processes laser radar sensor data at sensor data rates, identifies OOI (with confidence values), rejects non-targets/clutter, and provides inputs to the sensor fusion ATR. The sensor fusion ATR processes data from the laser radar sensor, FLIR NFOV mode, laser radar ATR, and FLIR NFOV mode ATR for fusion processing. As a minimum requirement, the fusion processor updates the target confidences provided by the FLIR NFOV mode ATR with the information provided by the laser radar ATR at the laser radar data rate. The ATR subsystem will report FLIR NFOV ATR results only, laser radar ATR results only, and fusion of laser radar and FLIR NFOV ATR results for performance comparison.

3.0 DEMONSTRATION AIRCRAFT

The aircraft initially chosen for the IRTS demonstration was the Airborne Seeker Evaluation Test System (ASETS) C-130 aircraft operated by the 3246th Test Wing, Eglin AFB FL. This aircraft has a retractable turret which houses the sensor subsystem. The Field of Regard (FOR) of the ASETS turret is very large and more than sufficient to exercise all the planned IRTS function.

4.0 IRTS DEMONSTRATION SCENARIO AND CONCEPT OF OPERATIONS

The IRTS demonstration flights will be conducted at low altitude (approximately 500 feet) against a variety of targets, ranging from unconcealed targets set in a benign, uncluttered background to camouflaged targets set against and within dense clutter. It is helpful to consider the nominal ranges of the demonstration flights to be broken into 3 blocks. Figure 5 provides a block discription of the concept of operations.

4.1 5-10 km Range

The aircraft will enter the demonstration area in the AOI search mode. In this mode the operator will search for AOIs such as hot spots, tree lines, etc. using the FLIR wide field of view (WFOV), 6 X 6 degrees. IRTS will develop a track file on each AOI and these track files will be handedoff to the FLIR NFOV ATR.

4.2 3-5 km Range

At approximately 5 km, the operator will lock the FLIR narrow field of view (NFOV) on the selected AOI via the FLIR tracker, and the FLIR ATR system will begin looking for objects of interest (OOI's). The FLIR ATR will perform segmentation and object detection operations at 30 frames per second on the NFOV FLIR image. Using a fast random access scan, the laser radar can provide the range and other supplemental features of each OOI to the FLIR NFOV ATR. The ATR will also use information provided by digital terrain maps and tactical decision aids (TDA) to reduce false alarms. The digital terrain maps will provide contextual information, and TDA (Tactical Decision Aid) will provide expected sensor performance, i.e., expected detection ranges, based on the input weather and target information. During the target acquisition process, the FLIR tracker will be used to track

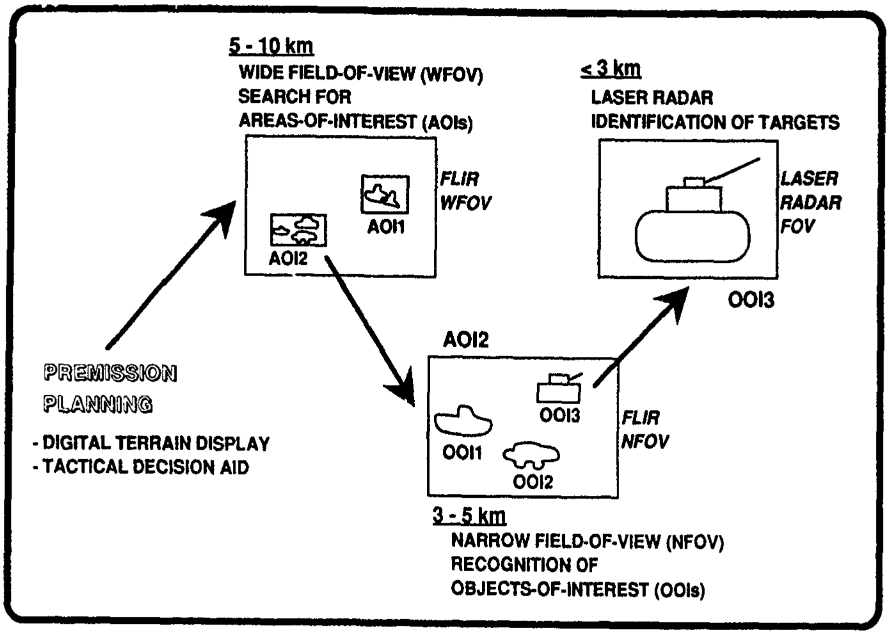


Figure 5. Concept of Operations

the OOI to keep the FLIR NFOV pixels registered to within a pixel from frame to frame. This tracking information will be used to facilitate pixel mapping between the FLIR NFOV mode and the laser radar.

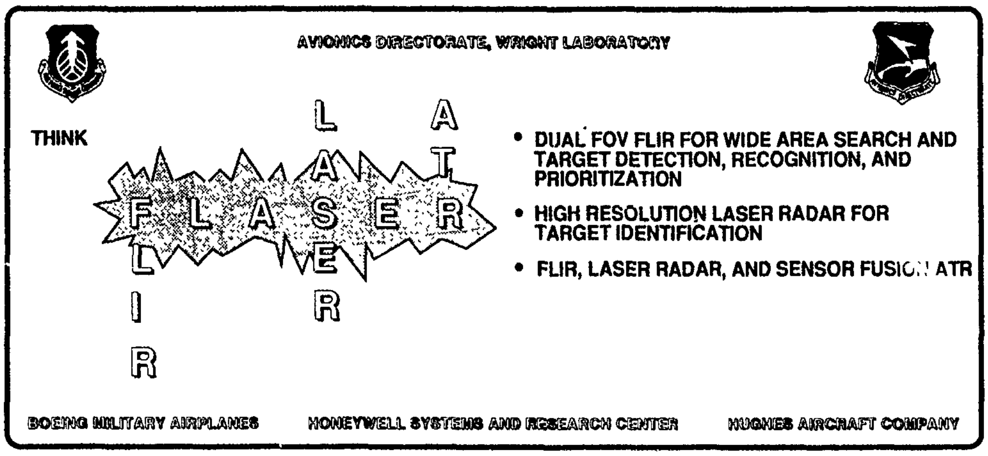
4.3 Less Than 3 km Range

When the range to the chosen OOI closes to approximately three kilometers, the laser radar will begin imaging the chosen OOI. The registration of the laser radar pixels to FLIR pixels will be such that the laser radar will only need to scan the detected target plus a minimum of additional background pixels as necessary to ensure that the total target is covered and enough background is covered to satisfy the requirements of the sensor fusion ATR. The results of the laser radar ATR will be reported to the operator in flight. Due to budget constraints, full FLIR ATR processing and sensor fusion processing will be conducted post flight.

5.0 PROGRAM STATUS

Boeing Military Aircraft (BMA) is the prime contractor for IRTS. BMA issued a Request For Quote (RFQ) in August 1990 soliciting sensor subsystem and/or ATR subsystem proposals for IRTS. At that time a 48 month program was envisioned. Several companies responded with sensor and/or ATR proposals. In January 91 the Air Force severely reduced the funding level of the program for FY91, providing only a "keep alive" level of funding. This level of funding allows BMA and the sensor and ATR subcontractors to work on system concept trade studies and design issues. If funding becomes available in FY92 the program will be ramped up, with an anticipated 30 month program ending in mid FY94.

The sensor subsystem contract was recently awarded to Hughes Aircraft Company, Electro-Optical and Data Systems Group, El Segundo, CA. The ATR subcontract was awarded to Honeywell Systems and Research Center, Minneapolis MN.



6.0 CONCLUSION

The purpose of IRTS is to demonstrate the performance improvements which can be obtained by combining advanced FLIR and laser radar sensors and ATRs. The program emphasizes integration of advanced sensors, processors, and algorithms. To minimize risk and cost, existing sensors, processors, and algorithms are to be used wherever possible. IRTS is a preliminary step toward the FLASER sensor concept.

DISCUSSION

1. DISCUSSOR: **Mr D.LEVAILLANT** (France)
(NU).
1) What kind of Aircraft is planned for the flight test of the FLASER ?
2) What is the expected CPU-Power for ATRs processing ?

AUTHOR'S REPLY:
(NU).
1) C-130 is planned as a testbed A/C. Miniaturization of components is not required to fit into pod size during this phase of the program.
2) The actual/expected CPU-Power requirements for ATR processing is limited to what is available on the ASETS (C-130) A/C.

2. DISCUSSOR: **Mr M.JACOBSEN** (Germany)
(NU). Can you comment on the performances of the LASER RADAR under various weather conditions ?

AUTHOR'S REPLY :
(NU). Naturally high humidity will attenuate the laser, but specifically we are estimating a 3dB/Km attenuation of the signal in fog conditions.

3. DISCUSSOR: **Mr J. DANSAC** (France)
(NU).
1) Le RADAR-LASER utilise-t-il un Laser/CO2 ?
2) La détection est-elle hétérodyne ?

AUTHOR'S REPLY:
(NU).
1) Yes, it is a CO2 Laser.
2) No, for the moment, it is not Heterodyne detection. It will be in future.

AIRBORNE EXPERIMENTAL FLIR PROGRAM

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Summary

The German Air Force has decided to build a FLIR system in order to derive and to consolidate the different technical requirements for their different tactical tasks.

Under a contract of the German MoD this FLIR system was designed and built on the basis of available and proven technologies. The equipment is pod-mounted inorder to avoid modification of existing TORNADO aircraft.

Two different modes of operation are comprised in one hardware. These are:

- o Navigation Mode; as a pilot aid for flying at night and in adverse weather
- o Fire Control Mode; for passive targeting and navigation-update

The mechanical and optical design will be presented as well as the electronics architecture. The performance of the sensor system will be described.

1. Introduction

The Experimental Flir System is based on a concept established in 1986 and designed to be flown under a TORNADO aircraft in an external pod (Fig. 1).

The imaging part is based on improved Common Module (CM) technologie with a digital scan converter as a video signal transformer of the IR scene.

The main goals of the program are summarized in the following:

Navigation Mode:

The pilot shall be assisted by a thermal image during night and adverse weather operations. Flight test with a Helmet Mounted Display shall be supported.

Fire Control Mode:

For position update prior to weapon release a position update with the radar is performed. In order to reduce detection probability this active procedure shall be replaced by a passive one. The passive system is an IR-system with the functions "target tracking" of well known targets (e.g. way points) and "passive ranging" on the basis of triangulation.

The hardware is in the final integration phase and will be flown in early 1992 on a German test range.

2. Mechanical and Optical Design

The design was determined by some major technical reqirements

- o use of available technologie and components to reduce risk
- o two different modes of operation
  - * navigation aid
  - * fire control
- o large field of view
- o long detection range
- o pod mounted
- o provisions for future update

This led to a modular design with 4 main modules:

- o Stabilized Flir Sensor
- o Infrared Imaging Unit
- o Pod Section (government furnished)
- o Electronic Part with 5 electronic boxes

2.1 Stabilized FLIR Sensor

The Stabilized FLIR Sensor (SFS) in shown in Fig. 2 in detail, while Fig. 3 gives a more simplified view of the SFS.

The SFS is fixed mounted on the rotating part of the roll-gimbal with unlimited rotation (n x 36o°) with respect to the x-axis.

Within the roll-gimbal there is the elevation assembly. The elevation axis is perpendicular to the roll-axis. It has unlimited freedom of (n x 360°).

The most inner part of the SFS is a stabilized mirror with two degrees of freedom. This mirror is controlled by the stabilization control loop, while the elevation assembly is only slaved to the elevation motion of the mirror.

The incoming radiation passes the entrance window and is reflected from the mirror out of the elevation assembly. Thereafter the beam is in the rolling part of the head-assembly. It passes through two telescopes. One of them is designed as a magnification changer.

The magnification changer produces 3 different Fields Of View (FOV). These are

- o Navigation - Mode
  10.7° x 14.3°
- o Fire-Control-Mode (medium)
  5.0° x 6.6°
- o Fire-Control-Mode (narrow)
  1.66° x 2.21°

For special missions, mainly for flight tests with a Helmet Mounted Display (HMD), a fourth FOV is realized. The FOV is specified with 16.8° x 22.4°. When this FOV is flight tested, part of the optical system is removed and replaced by other optical elements.

Between the magnification changer and the second telescope a special optic is installed to control focus. Defocussing happens because of two reasons. One is the normal geometrical/optical blurring and the other reason is focus movement of the Germanium-optic. There is an special digital control loop to compensate both effects. The output of the control loop moves a lens to refocus the image.

In the intermediate focal plane of the second telescope system there are the Thermal Electric Coolers (TEC) which give a reference temperature to the dc-restauration system for black/white clamping.

Before leaving the rotating part of the sensor head the beam passes an image derotation prism. This prism is needed because an elevation movement of the inner axis causes an image rotation. This image rotation has to be compensated for.

With two exceptions the optic is manufactured of Germanium (Ge). The material for the entrance window is Zinc-Sulfid (ZnS) and that of the image derotation prism is Gallium-Arsenid (GaAs).

Within the fixed part of the head assembly there is the Infrared Imaging System (IIS).

2.2 Infrared Imaging System

The Infrared Imaging System (IIS) consists of

- o the scanner
- o the Germanium lens system
- o the detector/cooler assembly

Basis of the IIS is the US-Common-Module-Technologie (CM) for thermal imaging equipment. Some modifications have been made to the US-CM components.

The US-CM System uses a scanner with a 2:1 interlace with the result that the number of videolines is twice as much as the number of detector elements.

In this program a better resolution was required. To meet this requirement a 4:1 interlace was developed. Thus the 145 detector elements give 580 TV lines, which in fact meets the European TV standard CCIR. The 4:1 interlace gives better resolution and better range performance.

The line sequence is as follows:

On the first forward stroke the 1. video line is generated. On the first fly-back the 3. line, on the second forward stroke the 2. line and on the second fly-back the 4. video line is generated.

The Germanium lens system focusses the IR radiation on the IR detector array.

The detector/cooler assembly consists of the IR detector and a linear drive cooler. The detector is an array of 145 elements. These elements are cooled by a linear drive cooler down to 77 Kelvin.

To generate a video signal from the detector signals a Digital Scan Converter (DSC) is used. Apart from producing a video signal in CCIR standard the DSC has the following functions:

- o automatic gain and level
- o automatic image optimization
- o black/white clamping

2.3 Stabilization

The stabilization control loop has different functions in the different modes of operation of the aircraft:

- o fixed line of sight (LOS)
- o pointed LOS

2.3.1 Fixed LOS

In the navigation mode the Flir video is displayed on the Head-Up-Display (HUD). In order not to confuse the pilot the Flir -FOV has to be the same as the HUD-FOV and the LOS must be fixed with respect to the aircraft reference system.

2.3.2 Pointed LOS

The LOS is not fixed to the

aircraft reference system (Fig. 4), but is stabilized to inertial space. The stabilization decouples the LOS from angular disturbances. This mode consists of the following 4 submodes as

- pure inertial stabilization without pointing, but with compensation of earth-rate and transport-rate
- external LOS control performed by joystick, video tracker or Helmet Mounted Sight (HMS)
- computer tracking executed by the FLIR computer with the knowledge of target location and own ships movement
- range calculation and position update without radar operation by triangulation

2.3.3 Inertial Stabilization

The stabilization control loop for inertial stabilization mainly controls the stabilized mirror with respect to two axes.

The stabilized mirror has an angular freedom in elevation of n x 360° and +/- 10° in azimuth. As a reference for the LOS stabilization a dynamically tuned gyro (DTG) is used. The DTG is directly mounted on the stabilized mirror gimbal.

Resolvers are used to measure the displacement with respect to the housing. These resolver signals are used to close LOS control loops. For pointing angles in azimuth greater than +/- 10° the roll gimbal is activated.

As soon as the stabilized mirror moves in azimuth the roll gimbal is slaved to this movement. The more the roll gimbal overtakes azimuth pointing function the azimuth position of the stabilized mirror goes to zero.

This mechanization is needed to meet high dynamic requirements which can not be met with the slow roll gimbal alone. Therefor there is a stabilized mirror for the high dynamic motion and the roll gimbal for the slow motion.

3. Electronic Architecture

Fig. 5 shows the block diagram of the Experimental Flir with its functional electronic components.

3.1 FLIR Computer

The FLIR computer (FC) is the central part of the electronics. The processing unit is a Motorola MC 68020 CPU running at 16 MHz. In order to accelerate the mathematical computation an arithmatic coprocessing unit MC 68081 is used. Because of the good multiprocessor capability a VME-Bus was selected as the internal communication bus.

The software is written in C because of the severe time constraints that could not be satisfied with an Ada program. The program consists of the following 5 main modules

- o LOS control with pointing functions commanded by the pilot, image derotaion and switching the fields of view
- o Passive Ranging carried out by a procedure that uses LOS angles for range computation. A triangel is determined (Fig. 6) by two aircraft positions (distance of several seconds) A and B and a fixed well known target C on the ground (e.g. way point). Knowing two angles δ 1 and δ 2, one at aircraft position now and one several seconds ago, and the distance between the two aircraft positions c the range to the target can be calculated.
- o Computer Tracking

  The LOS is permanently pointed on to the target by calculating LOS command. LOS command is derived from known target position and aircraft movement. To get aircraft position and velocity a Laser Inertial Navigation System (LINS) is pod mounted.
- o Built in Test

  Dependent on the actual mode of the FLIR system a selftest is carried out and reported to the pilots display.
- o Monitoring

  This is a special mode for on-ground testing of all functions the FLIR computer hat to execute.

3.2 LOS

The components of the LOS stabilization consist of torque motors, resolvers, dynamically tuned gyros and the image derotaion prism.

3.3 LOS - Control

This block comprises the analogue hardware for the LOS control loops. In Fig. 7 a typical control loop is shown for the azimuth stabilization loop as an example.

3.4 TI/DSC/AF

The subsystems IIS, DSC and autofocus, already desrcibed earlier, are combined in that block.

3.5 FCP/FHC

The FLIR Hand Controller (FHC) and the FLIR Control Panel (FCP) are located in the rear cockpit for FLIR operation (Fig. 8).

3.6 Video Tracker

This is a subsystem to control the LOS so that it stays on a designated target.

3.7 LINS/MILBUS

The LINS is used to give data of aircraft position and veeocity for computer tracking. The interface between FC and LINS is a Mil 1553/B-Bus with the FC as the master.

4. Performance

4.1 Modes

The following modes are realized:

- o Navigation Mode
  - * fixed great FOV
  - * stow position for protecting the entrance window
  - * no image derotation
  - * LOS stabilization on request
- o Fire Control Mode
  - * inertial stabilization
  - * 3 FOV
  - * steerable LOS
  - * image derotation
  - * triangulation for passive ranging
  - * computer tracking

4.2 Stabilization and Pointing

4.2.1 Field of Regard

Elevation	+20° /	-120°
Azimuth	+90° /	- 90°

4.2.2 LOS speed

Elevation 0.2 mrad/s / 2 rad/s
Azimuth 0.2 mrad/s / 2 rad/s

4.2.3 Pointing Accuracy

Elevation 0.1 mrad (+20°/-120°)
Azimuth 0.1 mrad (+10°/-10°)

4.2.4 Stabilization Accuracy

Elevation	0.05 mrad
Azimuth	0.05 mrad

4.3 Infrared Imaging System

4.3.1 Entrance Pupil

FOV #1	180.0 mm
FOV #2	75.0 mm
FOV #3	34.8 mm
FOV #4	21.8 mm

4.3.2 Fields of View

FOV #1	1.66° x 2.21°
FOV #2	5.0 ° x 6.6 °
FOV #3	10.7 ° x 14.3 °
FOV #4	17.1 ° x 22.6 °

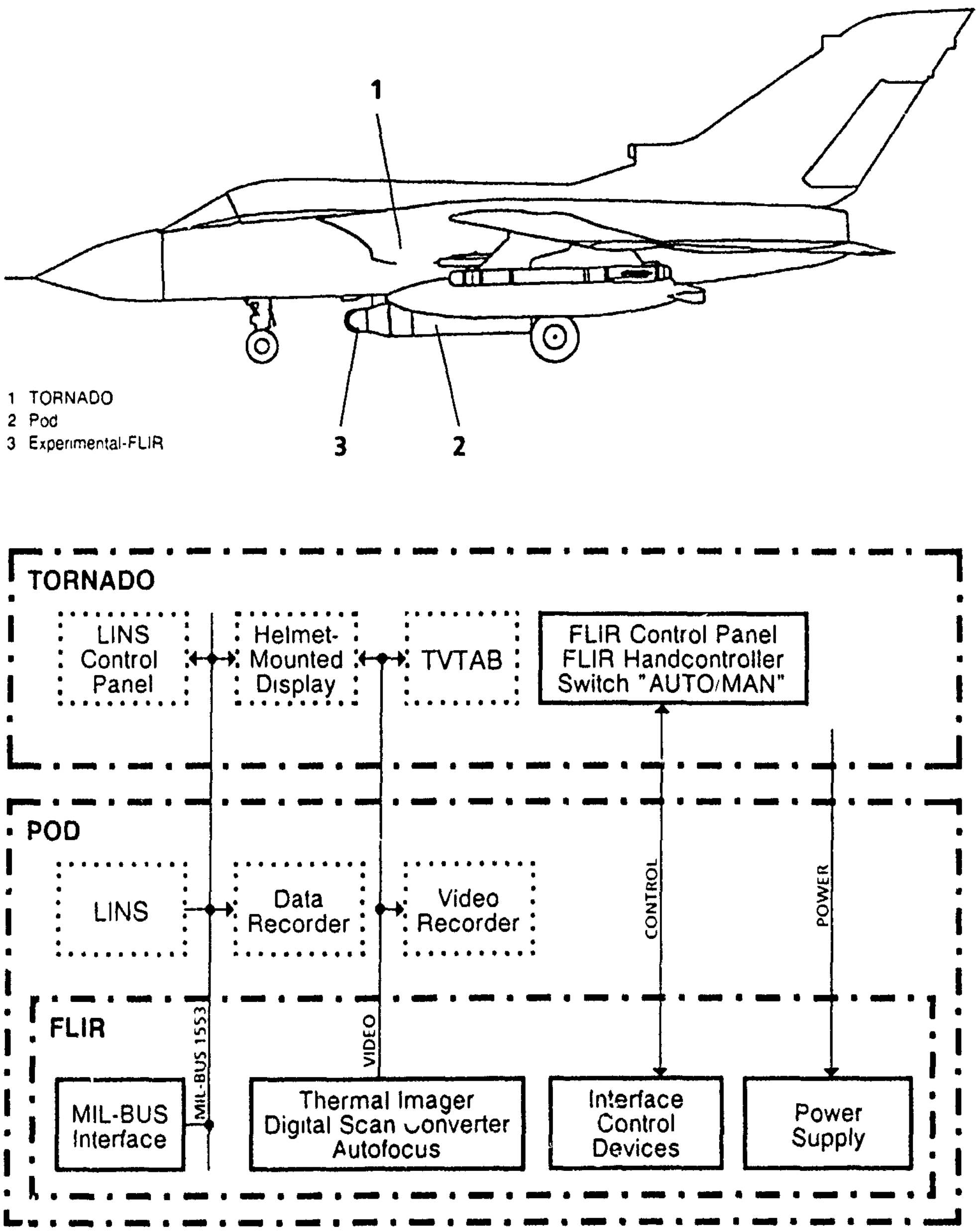

Fig. 1 Experimental FLIR System

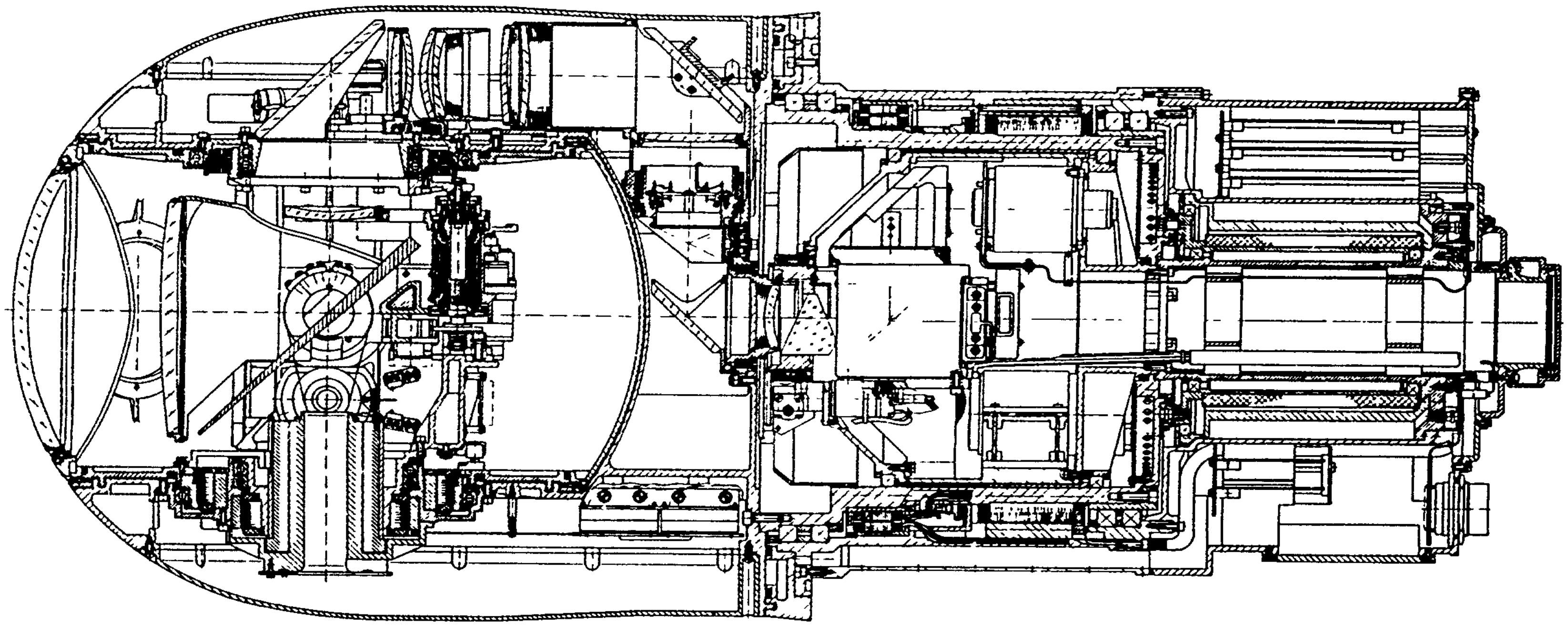

Fig. 2 Stabilized FLIR Sensor (detailed)

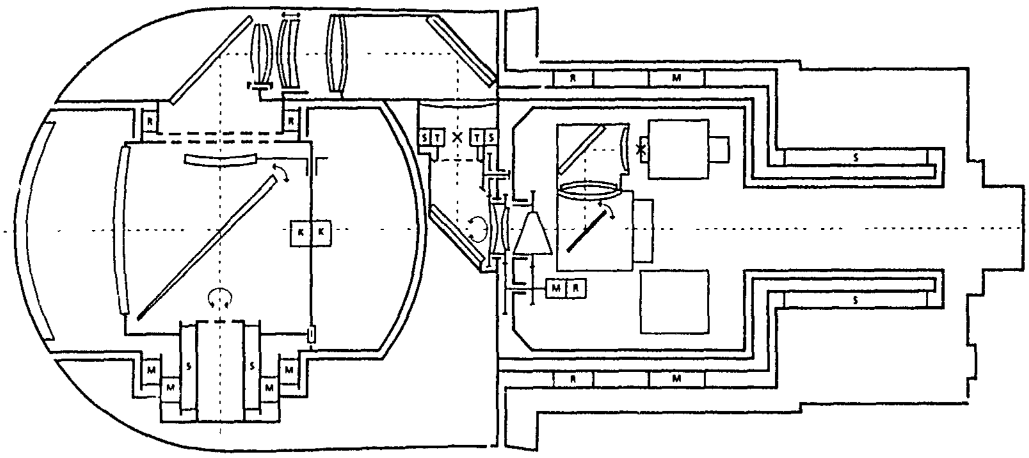

Fig. 3 Stabilized FLIR Sensor (simplified)

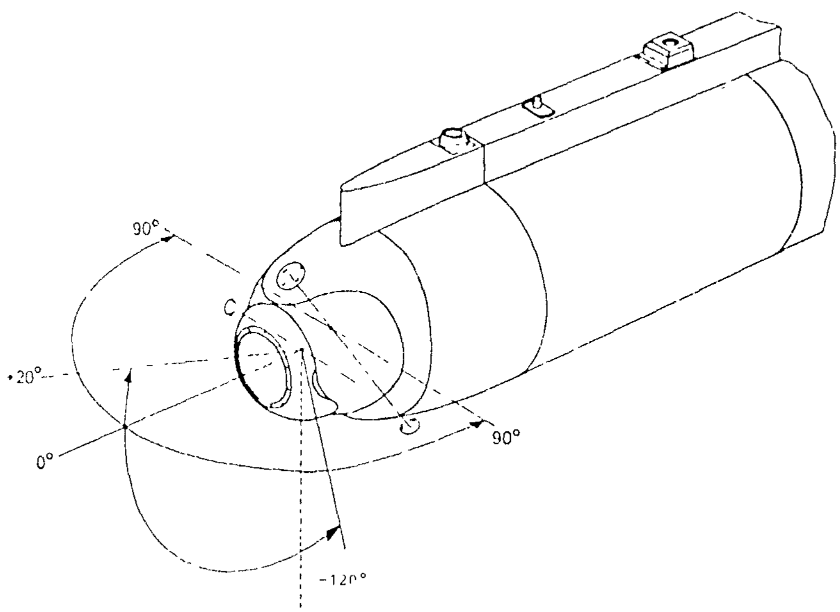

Fig. 4 Pointed Line of Sight

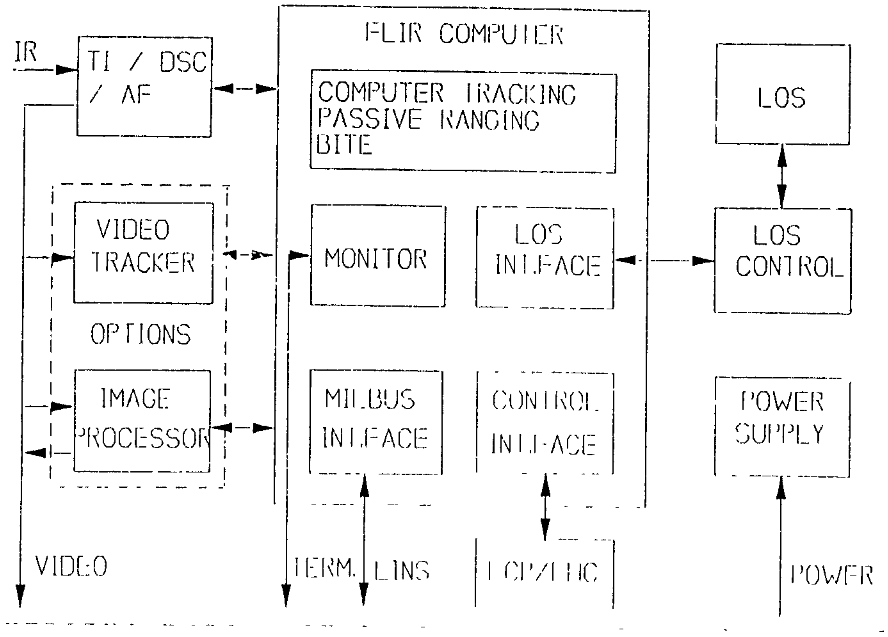

Fig. 5 Electronics Block Diagram

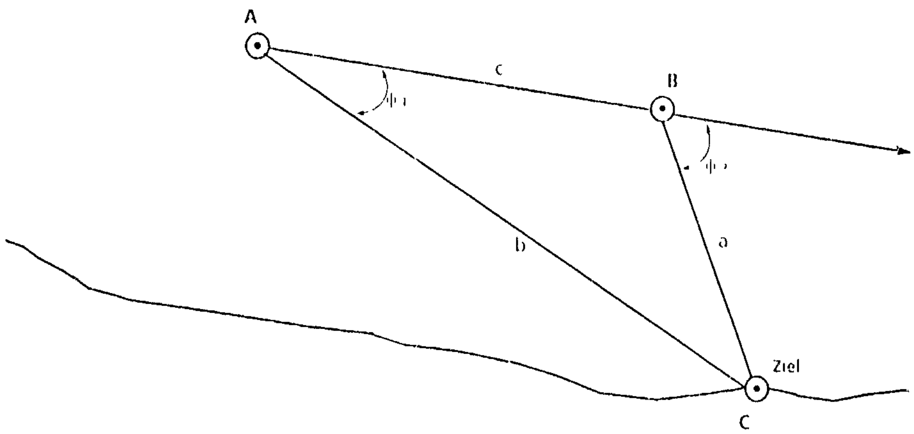

Fig. 6 Triangulation

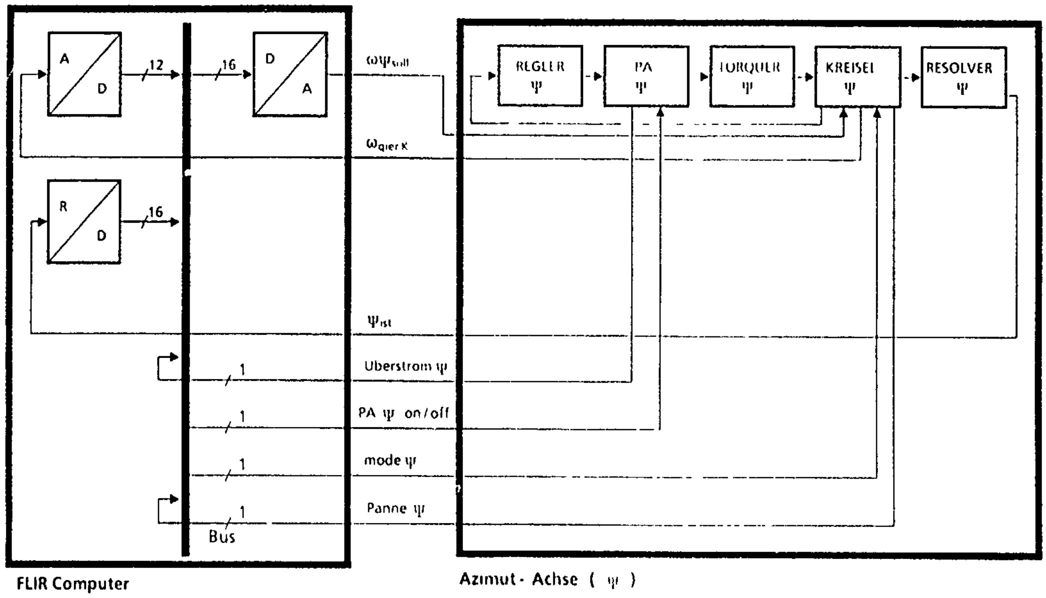

Fig. 7 Azimuth Stabilization Loop

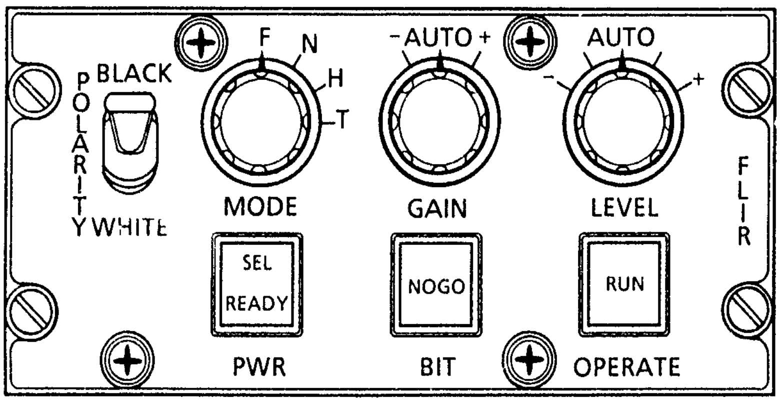

Fig. 8 FLIR Control Panel

DISCUSSION

1. DISCUSSOR: **Mr J. DANSAC** (France)
(NU). You have shown a table on Identification, Recognition, Classification, Ranges, etc... What is the type of target ?

AUTHOR'S REPLY :
(NU). The target for the shown range calculation is a shelter.

2. DISCUSSOR: **Col. MATHE** (France)
(NU). Développez-vous un Viseur/Visuel de casque spécifique pour votre programme FLIR ?

AUTHOR'S REPLY :
(NU). Actually, there is no development for a specific HMD at CARL ZEISS. A Data Interface (MIL.1553.B bus) and a Video Interface (CCIR-Standard ; STANAG-3350) are provided.

3. DISCUSSOR: **Mr T. FERRE** (France)
(NU). Pouvez-vous préciser la manière dont est réalisée la dérotation d'image. Est-ce optique ou par le biais d'une transformation numérique ?

AUTHOR'S REPLY :
(NU). In order to compensate for image rotation caused by LOS movement, the Elevation angle is measured and read into the FLIR computer. A digital control loop operates the derotation prism. For compensation of the influence of the aircraft movements, the appropriate aircraft angles are transformed into COS REFERENCE system.

THE GERMAN ANTI TANK HELICOPTER PAH 2 - AN EXAMPLE OF A FUTURE SENSOR PLATFORM

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SUMMARY

The german antitank helicopter PAH 2 is presently under full scale development, together with the french antitank helicopter HAC and the french support helicopter HAP, in a cooperation between Germany and France. It represents the current state of the art concerning target acquisition and fire control systems for helicopters in Europe.

The targeting system consists mainly of a mast mounted platform housing several sensors operating in different spectral ranges. It is used for the detection, recognition and identification of targets at increased ranges as well as to aim and guide 2nd and 3rd generation anti tank missiles. Further sensors and systems are available to support the crew in target acquisition or detection of threats in the battlefield and to support coordination of several helicopters in a flight, resp. the tasks of the flight leader and his coordination with the command post.

1. INTRODUCTION

The task of the PAH 2 is to support ground troops in the tasks of defending their territory against armoured vehicles in order to build up a concentration of defensive forces. This task is done by one or several flights under control and planning of the regiment headquarters who orders such operations to the support of a specific brigade or battalion in his area of operation. A flight consisting of seven helicopters including the leader coordinates with the brigade or battalion and internally to cover the area of operation.

As a result, the task and functions of a PAH 2 are depending on several levels of integration: Primarily, the information of the systems and sensors onboard have to be coordinated and integrated to provide sufficient and clear information to the crew consisting of a pilot and a commander to perform their primary mission task. As part of this level of integration also information from other members of the flight and the flight leader may have to be considered. At the highest level the flight leader ensures integration of the information gathered during the mission to the overall operations planning of the regiment and, vice versa, ensures flow of information regarding the updated overall tactical situation for the individual helicopters as far as it is relevant.

Consequently, the avionic system layout has to consider these various levels of "integration":

- targeting sensor level
- avionic system level
- operations level.

This paper will provide some detail information on the avionic system of the PAH 2, the german variant of the TIGER weapon system, with special regard of a.m. aspects.

2. AVIONIC SYSTEM LAYOUT

2.1 General

The general architecture has to take into account the functional requirements for the variants (anti tank PAH 2, HAC and protection HAP) and - at the same time - some national differences in comm/nav equipment. Thus, the avionic system of the PAH 2 is consisting of a distributed network of intelligent subsystems arranged in

- a basic avionic system, including the bus/display, communication, autonomous and radio navigation, electronic countermeasures and flight control subsystems

- a mission equipment package (MEP) which includes the antitank subsystem (MMS, PARS3 and HOT armaments), the pilot vision subsystem (thermal imager and HMS/Ds), A/A subsystem Stinger and the MEP management subsystem (computer and controls).

The bus structure is based on MIL 1553B with two fully redundant controllers for each bus (BCSG for basic bus and MCSG for MEP bus). In addition, the BCSGs are serving as main controllers of the basic avionic system to ensure the moding and monitoring of the overall system. Information from utility systems (e.g. hydraulics, fuel, electric, engines) is collected via 2 interface units (RTUs) to allow monitoring of those systems for operational purpose (by the crew during the mission) and maintenance purpose (by recording defects on a data carrier for post flight evaluation).

2.2 Subsystem Description

- NAVIGATION: The navigation subsystem is based on a strapdown system (laser) with doppler, radar altimeter and air data sensors as additional sensors. The raw sensor data are hybridized in the strapdown computers to provide the data for display and for manual and automatic flight control. Low Airspeed is calculated within the Strap down computers using flight control position sensors. We are presently investigating the integration of a GPS system.

- FLIGHT GUIDANCE AND CONTROL: The flight control system is based on mechanical controls. In addition a digital duplex flight control system with limited authority is available, which provides - apart from basic stabilization and command augmentation functions (CSAS) - a variety of higher (autopilot) modes . Thus, the crew will be supported in all mission phases (cruise, transition, NOE, hover, etc.) by appropriate automatic functions in order to reduce workload.

- ELECTRONIC COUNTERMEASURES: As a basis for future extensions a radar and laser warning system will be integrated. The development will be based on a bilaterally defined threat scenario with the potential of adaptation to national requirements. The detected threat information will be evaluated by the RW/LW computer who will provide condensed information to the crew (audio and visual). The basic system contains growth capacity for integration of defensive countermeasures. An IFF transponder is also part of the basic ECM fit.

- COMMUNICATION: The tasks related to communication within the HC flight or with external ground stations is normally quite demanding for the crew. For PAH 2 new radios (VHF/UHF, VHF-FM and HF) are developed to ensure integration into communication networks of the future armed forces networks - this includes data link functions apart from normal voice communication. Control of the radios is done via the central display and control system (mainly CDUs). Emergency frequencies are also accessible from a dedicated "Radio Frequency Indicator".

- TACTICAL SUBSYSTEM: In combination with the network and data link functions of the VHF-FM and HF and the digital map generator the PAH 2 has capabilities for tactical mission planning. Tactical data may be loaded on ground, transmitted via data link or inserted manually by the crew and will be displayed on top of a geographical raster map. With these capabilities the HC commander/gunner is provided with accurate and timely information.

- MISSION EQUIPMENT PACKAGE: The crew has access to various sighting subsystems for fire control and piloting and to various armament subsystems. Main armament are the HOT and ATGW3 missiles. For self defence against aerial threats each HC may be fitted with up to 4 A/A STINGER missiles. The main sight for target acquisition and firing will be a mast mounted sight developed in the frame of the ATGW3 programme (OSIRIS with TI, TV and LRF). Its image may be displayed on MFDs in each cockpit or on the specific HID - the TI may be used as backup for piloting and may be displayed on the crews monocular HMD. For piloting the main sensor is a nose mounted TI (derived from the OSIRIS TI). Pointing devices for both crew members are HMS and for the gunner a hand controller/cursor.

- CONTROL AND DISPLAY SUBSYSTEM: This subsystem performs the global task of monitoring and control of the avionic and main nonavionic subsystems. The core of the system are 2 redundant main computers (BCSGs), 2 data acquisition units (RTUs) and 2 redundant mission computers (MCSG). The main interface to the crew are 2 CDUs and 4 MFDs. The SG functions for the MFDs is integrated in the BCSGs, for HMDs in the MCSGs. The RTUs acquire the data of most nonavionic subsystems (electric, engine, hydraulic subsystem, etc.) and provide them for failures or exceedances and display (on crew request or in case of detected anomalies). The MCSGs are monitoring and controlling the mission subsystems and provide to the BCSGs the essential information for control and display. The BCSGs are monitoring the complete system - using the data provided by the individual subsystems (including RTUs and MCSGs) and generate the interface to the crew - the crew interacts with the system mainly via CDUs and the keyboards on the MFDs. Detected failures will be indicated to the crew but will also be recorded for post flight evaluation by the maintenance crew. Pre and post flight checks are supported by CDU menus to detect and locate failures beyond the capabilities of the failure monitoring during normal system operation. Thus, the crew has access to all essential HC, navigation and tactical information and is not loaded with several routine tasks (as system monitoring). This is the basis to get rid off a variety of cockpit instruments in favour of the 2 MFDs and 1 CDU per crew station. Some instruments however remain for first engine startup, emergency purpose and to ensure higher integrity and availability of the system.

3. TARGETING SENSOR INTEGRATION

Tactical night deployment scenarios assume that an antitank helicopter will operate in an area dominated by obstacles. Flight profiles below 30 feet are preferred, such as NOE and extreme contour flight. Therefore, the precise determination of locations and obstacles is required to ensure crew safety and mission success. In the PAH 2 development phase a high performance armament and visionic system called **EUROMEP**, based on results of the ATGW 3 programme, will be established.

3.1 Night Flight Capability

As a prerequisite to night fighting, night flying capabilities are required. Night flight requires a level of concentration on the part of the pilot which exceeds the norm, especially when the operation requires a mission to be flown below 30 feet. The visual tasks of the pilot/copilot, as well as control activities, increase dramatically the closer the aircraft flies to the surface. Thus the wide range of night flight tasks must be divided between the two crew member of this tandem cockpit helicopter.

Starting with either conventional NVGs or piloting TI systems as night flying aids it was soon recognized (sometimes the hard way through crashes) that physics and ergonomy require information in more than one spectral range, in an interpretable manner in front of both eyes.

The **pilot visionic system** (PVS) being part of the EUROMEP system provides a **wide-field of view** (30 x 40 deg) IR piloting sight which consists of a **thermal imager** (TI) installed on a swivelling platform located in the TIGER nose. In addition, each crew member has a **helmet-mounted sight and display** (HMS/D), which orients the sensor according to the line of pilot or copilot sight. The PVS is used not only for the piloting function but also for air-to-air missile firing.

At present, studies for an **Integrated Helmet** System (IHS) are performed to provide the capability of **binocular/biocular vision** and a **second** sensor based on **image intensification tube** (IIT) technology. Another possible solution is the integration of a **Low Light Level TV camera** (LLLTV) together with the TI on the PSU. As a further improvement, a combination of features extracted from the thermal image and the (realistic) LLLTV image may be considered.

MBB/DASA and the German Army Aviation Corps have performed ground and flight trails with an IHS and a HMS on a PAH 1 respectively a BK 117 helicopter. In parallel investigations in our visionic laboratory have been performed with a GEC and Honeywell IHS.

3.2 Day and Night Combat Capability

As main sensor for ground targets within the EUROMEP system a GVI (gunner visionic) system with an **MMS** (mast-mounted sight) is chosen

o to reduce the exposure time during target acquisition combat phase
o to have a periscopic view from behind protective cover, with an overall view of nearly 360 degree in azimuth
o to reduce the visible, IR and also radar cross-section of the HC behind cover and thus to reduce the vulnerability
o to optimize the CG of the HC and
o to minimize the disturbance of sight windows from the exhaust missile gas.

The GVI consists of the following components

- Two-stage stabilized mast-mounted sight (MMS) platform

  o a high performance Thermal Imager (TI) with three optical FOVs and additionally three FOVs with underscanning using the IRCCD technology
  o a high resolution TV camera with three FOVs
  o a Laser Range Finder (LRF) in 10 m range working together with the TI
  o an Electro Optical Block (EOB) for locating the HOT missile

- Fire Control Computer/Display Processor and Alignment Processor
- Sight Electronic
- Target Tracker, tracking up to four targets
- Head-In Display (HID) for the missile guidance process
- Multifunction Displays (MFD) in the cockpit

Concerning the antitank armament, wire guided HOT missiles and fire and forget ATGW 3 LR missiles may be used.

The sight enables the gunner in association with the connected display to acquire and engage tanks at the distance of approx. 5000 m during day and night time using the different sensor FOVs. The image generated from the gunner sight sensors serve three purposes:

- **observation** by the gunner or in emergency case the pilot (FOV = 30 deg x 40 deg)
- manuell HOT or ATGW 3 LR **engagement** by the gunner
- **automatic image processing** for tracking and ATGW 3 seeker alignment.

The gunner can choose the sensor for observation depending on illumination and weather condition. For automatic image processing the signals of the TI or of the TV-camera will be used. The main optical sensor is for the day and night time application and for the ATGW 3 engagement the TI sensor. For ATGW 3 seeker alignment/lock on, a correlation of missile seeker image and MMS sensor image are performed.

The gunner can designate targets for automatic

tracking while he is observing either a TI or a TV image. Any changing of FOV with the same magnification will be done simultaneously for these sensors. Indication of the LOS direction and the status of the sight will be displayed as symbols on the monitor. The digital sight information would lend itself readily for automatic feature analysis using image processing algorithms. Presently, such a feature is not available within the ATGW 3 programme for HC applications. After availability it could easily integrated into the system thus reducing the gunner's workload further.

3.3 Avionic System Integration

The integration of the PAH 2 subsystems as described above is the basis for the functional integration on both the avionic system level and the operations level.

This section shall highlight some features of the weapon system achieved by functional integration of the Tactical Subsystem and the EUROMEP.

The following subsystem functions are involved in the examples:

- the Digital Map Generator (DMG) providing a map with overlays of tactical information,
- the Video Memory storing MMS sensor images, which can be evaluated in concealment,
- the Mission Data Transfer System (MDTS) and the Data Insertion Device (DID) for uploading and downloading of tactical data,
- the Data Link for updating the HC's internal database and for transmission of tactical information to other HCs or ground troops,
- the Mast Mounted Sight (MMS) as the main sensor for target acquisition.

3.3.1 *Predirection of the MMS*

The MMS can be predirected to targets, which have been marked on the Digital Map or using an image of the Video Memory. This feature allows for a NOE flight to the attack position and for fast target acquisition and firing.

The target on the Digital Map may have been uploaded from a database or may have been entered using the method as described in the next section.

3.3.2 *Passive Target Ranging*

The parallel use of the imagery provided by the MMS and of target information displayed on the DMG allows for an improvement of target ranging by comparing information from stadiametric ranging with map information. The imagery of the MMS is displayed on one MFD while the map overlayed with the LOS of the MMS is displayed on the other MFD.

If the target is not moving, the accuracy can even be enhanced by acquiring target information from different HC positions. The target position is the crossover of two LOS layed over the digital map image.

The Video Memory stores up to eight images of one of the sensors allowing for an acquisition and evaluation of a large part of the scene in concealment. All objects identified may be used as targets for immediate MMS predirection, target acquisition and firing.

3.3.3 *Maintaining the HC Tactical Database*

This feature forms part of the integration at operations level. The database of an individual HC is uploaded from MDTS and DID and presented as synthetical overlay on the Digital Map.

The information is updated during the flight to the forward position using the Data Link. This update occurs in a hierarchical manner: the leader of the flight is informed first and provides the information to the other HCs of his flight. The flight leader may transmit a subset of the information only.

This proceeding ensures a database as common as possible for all HCs of a flight.

The database may be updated using information acquired by the HC's systems or manually using information gained from combat troops.

Target informations may be handed over via Data Link from other HCs of the flight in order to coordinate attacks.

3.3.4 *Maintaining the Operation Center Tactical Database*

The database of the HC provides the latest available tactical information.

This information may be transmitted to the operations center via Data Link. In addition, the HC's database can be downloaded to the MDTS and read out at the basis.

DISCUSSION

DISCUSSOR: Mr M. JACOBSEN (Germany)
(NU). Can you comment on how passive Target Ranging is accomplished ?

AUTHOR'S REPLY :
(NU).

- On the first display, the perspective view as seen by the Gunner Sight is displayed. A Target, which may be positioned e.g. on a road, is marked. The distance is roughly measured using Stadiametric Ranging.
- On the second display, the Digital Map is shown. Once the target is marked, the LOS (present position to Target) is displayed. Because of the unaccuracy of the Stadiametric Ranging, the target mark will not be positioned on the intersection of the LOS and the touch, but some where else on the LOS.
- The correct distance information is gained by adjusting the position of the Target along the line of sight until it is located on the intersection of LOS.

NAVAL TARGET CLASSIFICATION AND DESIGNATION WITH THE CL-227 SEA SENTINEL

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Summary

The integration of the CL-227 UAV Sea Sentinel System with the Canadian Patrol Frigate (CPF) platform provides the naval target classification and designation capability meeting the mission requirements of this and following decade.

The present capability with manned aircraft is significantly enhanced including growth potential to match the continuing development of stand-off Anti-Surface Ship Missiles (ASSM) and the increased likelihood of coastal patrol mission requirements. The UAV System complements the manned aircraft in the areas of high air defence risk, poor weather, peak overloads, and routine tasks.

The low signature air vehicle permits covert, highly survivable missions. The modular mission payload capacity provides for a mix of single or combined high performance payloads with a high time on station.

Transmitting real-time high resolution imagery from the UAV to the ship from long ranges places significant demands on the payload data downlink. The selection of such a link must consider the present installed link capability, as well as interoperability requirements with other NATO ships.

The functions of mission planning, air vehicle and payload control, and data exploitation of the UAV System including data fusion, must be integrated into the ship platform. The architecture and capability of the Canadian Ship's Integrated Processing and Display System (SHINPADS) and the future NSA Shipboard Tactical Support System (STSS) of the CPF Combat System facilitate integration.

A Maritime UAV system designed to exploit the CL-27 Sea Sentinel and the CPF SHINPADS combat system offers an effective option for enhancing CPF with the ability to perform Over the Horizon (OTH) naval target classification and designation.

1. Introduction

Stand-Off Anti Surface-Ship Missile (ASSM) ranges far exceed surface ship surveillance and fire-control sensor system horizons. Naval Gunfire Support requires a remote (from the ship) observer's perspective, for accurate fall-of-shot correction. The Rules of Engagement in times of hostilities may require confident classification of target nationality, capability and intentions, before shots are fired. These facts pose tactical problems to both the offensive and defensive mission performance of every surface warship.

One classical solution to these problems has been to provide the ship's command with the support of one or more aerial observer Traditionally, these observers have been human occupants of manned lighter-than-air, fixed-wing or rotary-wing aircraft. Some such aircraft are capable of conducting part or all of the engagement, themselves. Others provide Over-The-Horizon (OTH) surveillance, detection, tracking and/or designation support to the engaging surface force(s).

Surveillance, detection and tracking are the ship's functions which most require horizon extension. Most classes of warship which are fitted with ASSMs, however, are not capable of carrying manned fixed-wing aircraft Lighter-than-air manned aircraft are not commonly available . support of modern navies, and rotary-wing manned aircraft are often too vulnerable to surface-to-air missile attack to be able to serve in the required OTH mission roles, without incurring high risks

The capability to carry out this role is necessary in a variety of scenarios. For Canada a common scenario is that of peace keeping. Others include neutral operations in the neighbourhood of hostilities and non-neutral operations prior to and during hostilities. Support to civilian operations such as anti-drug operations and fishery operations must also be considered.

Recent wartime experience has confirmed the substantial practical value of Unmanned Air Vehicle (UAV) support for precisely these high-risk mission support roles UAVs have

been demonstrated to provide Target Detection, Target Classification, Fall-of-Shot Observation and Battle-Damage-Assessment support to surface warships, in active combat Experience has shown that VTOL UAV systems should be used.

The capability to carry out the key role covertly is an important advantage of the CL-227 Sea Sentinel UAV System due to its low signature air vehicles. A further advantage is the capability to carry alternative or multiple payloads suitable for the role of over-the-horizon target acquisition, classification and designation with an appropriate endurance. The system also imposes minimal demands on the ship platform infrastructure. Sea Sentinel's Vertical Take-Off and Landing (VTOL) capability clearly makes her an attractive choice for retrofitting onto a wide range of ship classes. As a Standard Maritime UAV, Sea Sentinel has demonstrated VTOL operations off the deck of ships to both NATO and US forces. In the JANTIDE and most recently in the MAVUS programs, the Canadair Sea Sentinel has demonstrated providing OTH support to surface ships.

In this paper, some of the issues and benefits associated with retrofitting such a Maritime UAV system into a helicopter-carrying frigate are reviewed.

The frigate discussed is the City Class Canadian Patrol Frigate (CPF) The CL-227 Maritime UAV System discussed is comprised of.

1 Air vehicles;
2. Modular Mission Payloads;
3. Launch and recovery subsystem;
4. A ship-to-UAV data uplink function,
5. A UAV-to-ship data downlink function.
   a. Status monitoring downlink
   b. Payload data downlink,
6. Mission Planning/Control Functions·
   a. Mission planning;
   b. Air Vehicle Control;
   c. Payload Control;
   d Data Exploitation

The CL-227 is discussed in section 2 Section 3 presents a high-level overview of the CPF, and of its combat missions.

A discussion of the launch and recovery subsystem is beyond the scope of this paper, but there is mention of the impact of the recovery phase requirements on the ship-to-UAV uplink design decisions.

Section 4 proposes alternative strategies by which a UAV System might be implemented, on a CPF, with a perspective on the relative merits and problems of each approach

The paper concludes that a Maritime UAV system designed to exploit the CL-227 Sea Sentinel and the CPF SHINPADS Combat System offers an effective option for enhancing CPF with the ability to perform Over the Horizon (OTH) naval target classification and designation.

2. The CL-227 Sea-Sentinel

2.1 Development History

The CL-227 UAV system was originally conceived as a close-range battlefield surveillance and target acquisition system. A Maritime version of the CL-227 has also been developed, to support short range naval operations. The development of the land and maritime configurations has continued in parallel, with a high degree of commonality and synergy. Figure 1 shows the CL-227 air vehicle concept.

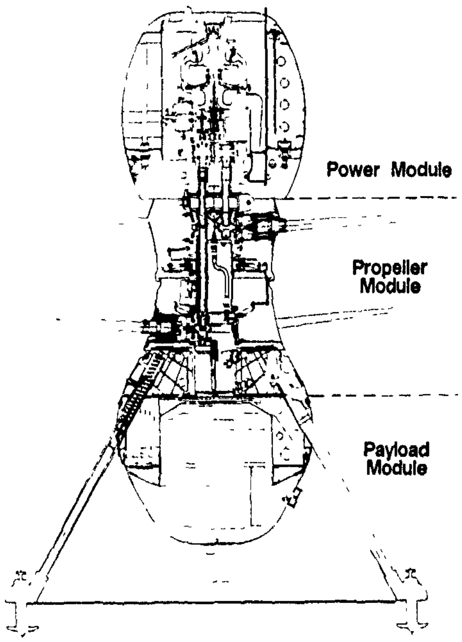

Figure 1 CL-227 Air Vehicle Concept

Proof of concept flights were carried out in the period 1977-1980 In 1981-1982, flights demonstrated a representative system using a stabilized vidicon camera and commercial microwave command and data link

In 1989 Canadair started development of a militarized prototype system. A joint US/Canadian evaluation was conducted in 1989 and 1990 to evaluate the system for Army, Navy and Air Force missions.

Over 500 CL-227 flights have been successfully conducted in either a tethered or free-flight mode.

2.2 Sea Sentinel Development Status

From 1986 to 1989, the team of Canadair, Indal Technologies and Paramax Electronics Inc carried out design studies for the USN and DND on a sea variant of the CL-227 Sentinel System. Systems engineering studies were carried out to define a launch and recovery system (Ref.1,2) including a simulation model to establish landing accuracy. Ship motion and sea condition data were based on the methodology developed in work for DND and USN NATC (Ref.3)

The Maritime Electronic Warfare Payload Development System (MEWPADS) study, commissioned by the DND Directorate of Maritime Combat Systems (DMCS), established the feasibility of a CL-227 Sentinel System operating from a ship in an EW role. The study identified suitable NDI ESM and ECM sensors and evaluated the enhancement of the ship's EW capability (Ref.4). In particular an analysis was carried out on targeting mission performance using an ESM payload.

Based on the studies, in 1989 a demonstration Sea Sentinel System was developed and a dual demonstration carried out. Take-off and landing from the US Army ship JANTIDE was demonstrated to NATO Special Working Group (SWG) 11. A surface ship OTH support mission demonstration was carried out in conjunction with the PEO-IEW Small Aerostat Surveillance System (SASS), operating off the JANTIDE (Figure 2 shows a landing on the JANTIDE). SASS comprises an radar payload carried by a airship tethered to a ship with the monitor The exercise used the SASS radar to search a wide area and to cue, in real time, locations of suspect targets for the CL-227 to classify.

The JANTIDE exercise (Ref 5) showed.

i. viability of vectoring a UAV to a surface target, using radar contact data
ii. real time visual classification data relayed from a UAV imaging payload, in support of radar operations;
iii operational compatibility of the CL-227 system with an aerostat system,
iv viability of VTOL UAV launch and recovery, at sea

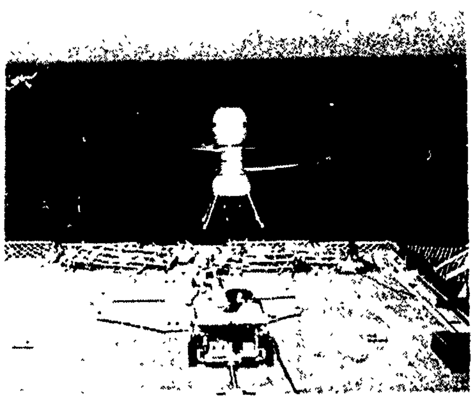

Figure 2 CL-227 UAV Landing on Ship

In 1990, the US DoD UAV Joint Project Office (JPO) awarded a contract to Canadair to integrate and adapt the proven CL-227 hardware with the Loral mission planning control system and data link equipment to maritime requirements. The contract includes an at-sea operational demonstration of VTOL UAV operations in support of a US naval ship in a NATO exercise. This Maritime VTOL UAV System (MAVUS) operational demonstration is scheduled to end in December 1991.

The multi-national NATO Project Group (PG)-35 Maritime Operational Demonstration includes American, Canadian, British and Dutch participation.

Exercises like JANTIDE and MAVUS confirm the viability of VTOL UAV mission roles and tactics in support of maritime forces.

2.3 CL-227 Improvement Program

The continuing evolution of NATO's Maritime UAV System requirements (through SWG-11 and PG-35) is establishing modular mission payload, data link, mission endurance and mission employment requirements.

Canadair is reviewing these requirements and investigating product improvements to maintain the CL-227's optimum response to requirements

Potential improvements to the baseline MAVUS CL-227 system include:

- a higher gross take-off mass with larger rotors
- an improved slightly larger airframe made of composite materials

- a higher power engine (such as the Williams WTS-117);
- a larger composite fuel tank;
- GPS for autonomous navigation ;
- ESM, Synthetic Aperture Radar, and mine detection payloads, in addition to MAVUS (FLIR, TV, communications relay and ECM) payloads;
- Ship Combat System integration concepts, to make maximum use of existing antennas, processors and ship consoles.

Upscaling the air vehicle has historically proven to be a negligible-risk project. Tables 1 and 2 present the performance data, and mass, respectively, for two configurations. One configuration provides a near-term capability and the other long term.

	NEAR TERM	LONG TERM	
		WITH SINGLE MISSION PAYLOAD	WITH MULTIPLE MISSION PAYLOADS
MISSION RANGE (NM)	70	100	100
TIME ON STATION (HRS)	0 6	> 2 0	> 1 0
TOTAL MISSION TIME (HRS)	> 3 0	> 4 0	> 4 0
MAXIMUM MISSION RANGE (NM)	> 85	> 100	> 100
MAXIMUM ENDURANCE (HRS)	> 3 25	> 5 0	> 5 0
LOITER AIRSPEED (KTS)	39	50	50
CRUISE AIRSPEED (KTS)	60	80	80
MAXIMUM AIRSPEED (KTS)	70	> 100	> 100

TABLE 1 PREDICTED PERFORMANCE

Notes:

1. Mission range shown is typical; maximum is greater than 100n.m.
2. Mission time is maximum endurance; 15 min. reserve excluded.
3. Modular mission payload is mission specific part of payload module.
4. Payload mass shown are for FLIR, FLIR with supplementary tank and multiple payload respectively.

	NEAR TERM	LONG TERM	
		WITH SINGLE MISSION PAYLOAD	WITH MULTIPLE MISSION PAYLOADS
MODULAR PAYLOAD WEIGHT (KG)	23	23	45
MAXIMUM TAKEOFF WEIGHT (KG)	215	350	350

TABLE 2 MASS

The proposed improvements result in a mission payload of 23 to 40 Kg. Depending upon the mission requirements, the CL-227 Sea Sentinel can be capable of carrying multiple sensor payloads on the same mission, or a single payload and an auxiliary fuel tank. Figure 3 illustrates several modular mission payload options.

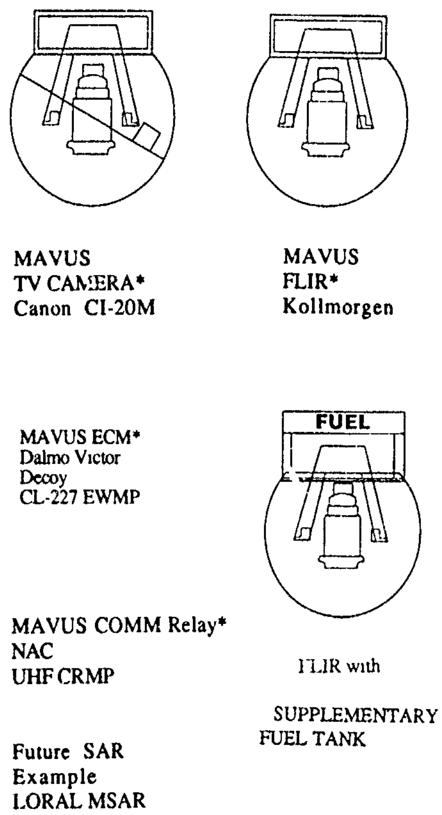

Figure 3 Modular Mission Payload Options

3. The Canadian Patrol Frigate (CPF)

3.1 General

The CPF is Canada's newest warship, and one of the most advanced frigates in NATO, today.

3.2 The Missions

3.2.1 The Primary Mission

The primary mission of CPF is Anti-Submarine Warfare (ASW).

Fitted with both active and passive ASW sensors, onboard torpedoes and an ASW helicopter, CPF is capable of performing in both inner and outer ASW screens.

The primary ASW mission requirements are

1. Search, Detect, Classify and Track all potentially hostile acoustic targets;
2. Report all acoustic targets to the Tactical Force Command,
3. Prosecute designated hostile targets

3.2.2 The Secondary Missions

CPF is also capable of performing both air and surface warfare missions.

CPF surveys the above-water horizon, with both long and medium range area surveillance radars, a Close-in-Weapon system surveillance radar, a broadband RF intercept/DF system, and an Electronic Support Measures (ESM) system.

CPF is capable of engaging hostile air targets with coordinated combination of: Electronic Countermeasures (Onboard and Offboard); Vertical Launch Sea Sparrows, the 57mm Rapid Fire gun, and the CIWS gatling gun.

CPF is capable of engaging hostile surface targets with the HARPOON ASSM, the 57mm gun and the CIWS gatling gun.

Although CPF may be tasked to perform any one of these missions to the exclusion of all others, CPF is specifically designed to be capable of engaging in all three warfare missions, simultaneously.

3.3 The CPF Combat System

The Canadian Patrol Frigate Combat System is an implementation of the Canadian Ship's Integrated Processing and Display System (SHINADS) concept

Unisys Corp AN/UYK-507 militarized general purpose processors are distributed throughout the ship, integrated via a redundant high-speed (10Mb/s) serial databus and the SDX distributed operating system.

The Combat Operations Room personnel manage the Combat System via Standard SHINPADS Display consoles, any one of which can be programmed to function in any available console mode. Each operator's tasks and responsibilities has been identified and grouped into a hierarchical menu of soft-key arrays. An operator selects the appropriate set of menus, by selecting the appropriate console "mode".

To the extent that an operator's duties can be adequately performed without interacting with dedicated system hardware, an operator can perform his tasks at any Standard Display.

The Hull Mounted Sonar, Sonobuoy Processing System and Fire Control System generate RS-343 video, selectable at any SHINPADS Standard Display consoles. The Video Distribution system is capable of routing either RS-343 or RS-170 video signals

The CPF SHINPADS system has an open architecture Adding new subsystems is achievable by one of the following strategies:

1. Subsystems which can be implemented as software on an AN/UYK-507, running under SDX, can be integrated directly into the existing combat system (subject to practical issues such as system resource requirements),
2. Subsystems which meet the first criteria, but exceed the available spare system resources, may be implemented by adding a new AN/UYK-507 which can still be interfaced to an existing or new processor to the bus,
3. Subsystems which cannot be implemented in an AN/UYK-507 can still be interfaced to an existing or new processor, via any of the following interface types:

   a. NATO Serial;
   b. Mil-Std-1397 (NTDS) Parallel;
   c RS-232C; or
   d Mil-Std-188C.

Sensor video provided by a new system can be routed to the existing Standard Displays, by adding new input channels to the existing Video Distribution System, if the video complies with either RS-343 or RS-170 standards.

The CPF SHINPADS databus is loaded to less than 10% of capacity. A minimum of 20% future growth capacity has been reserved in the system memory resources.

4. Employing a Maritime UAV System in Support of CPF

4.1 CPF ASuW Missions Which a UAV System Might Support

4.1.1 General

The CPF is already effective in its planned ASuW missions, without a UAV System. In situations where airborne support is required, CPF deploys the helicopter, or vectors assigned supporting aircraft.

The authors of this paper propose that the integration of a Maritime UAV System would further augment the CPF's overall mission effectiveness

Rather than proposing to replace the aircraft in these missions, we evaluate the manner in which UAVs might enhance the safety and effectiveness of current CPF/helo mission performance

In this section, the mission phases characteristic of the missions discussed are identified. In section 4.2, the exploitation of various UAV payload types are explored in terms of the requirements of each mission phase.

4.1.2 Supporting Long-Range SurfaceShip Engagements

The primary ASW sensor of the CPF is a Tactical Towed-Arrayed Sonar (TACTAS) TACTAS is not, however, exclusively useful for ASW.

TACTAS also provides CPF with the invaluable capability to passively detect and classify surface shipping which is over the (above-water surveillance) horizon

CPF can process the TACTAS data through a variety of Target Motion Analysis (TMA) functions, to track and localize those contacts.

The effective range of TACTAS is such that slow-moving surface targets at maximum sensor range would take hours to localize well enough for a HARPOON fire control solution. It would require less than half an hour, however, to localize such a target adequately well to provide an Area of Probability small enough to effectively survey with a UAV.

CPF presently employs its helicopter and/or third party aircraft, to investigate and prosecute their TACTAS contacts. A Maritime UAV system offers an alternative to exposing manned aircraft to the risk of hostile responses from the targets they investigate.

When the target is beyond CPF's radar systems horizon, likely mission phases are:

1. Surveillance: monitoring passive sensors, including TACTAS, DF, and ESM;
2. Detection: detecting possible targets, on one or more passive sensors;
3. Classification: estimating probable target type, capabilities and intentions, on the basis of detected signatures,
4. Localization: estimating probable target position, and possibly direction, range, course and/or speed, with uncertainties;
5. Tracking. refining the estimated position, course and speed data, and establishing an estimated state vector for the target, and
6. Engagement: planning and executing an attack against the target, conducting battle damage assessment, and responding, as appropriate, with self-defenses and/or additional hostilities

Throughout the mission, voice and tactical data link communications are also probable, between CPF, supporting aircraft, and/or other cooperating forces.

4.1.3 Supporting Coastal Patrol Missions

Coastal patrol mission present a number of unique problems.

Land clutter and shallow-water conditions compromise the ship's sensor systems, presenting solid barriers at relatively short distances (compared with open-ocean line of sight horizons).

In populated areas, local telecommunication and radar activities tend to clutter the electromagnetic spectrum, which tends to hamper the use of ESM. In hostile areas, land offers concealment and refuge to hostile land, sea and air forces.

The CPF relies heavily on aircraft support, in these missions, to provide warning and protection against threats like fast-attack aircraft, land-based anti-ship systems and fast-patrol boats.

A Maritime UAV system offers CPF the ability to deploy multiple air vehicles, providing simultaneous real-time coverage, over a wider area than one manned aircraft can survey. (The smaller size of the UAVs simply permits more UAVs than helos to be operated off the same ship.)

If hostile forces are suspected to be in a particular area, CPF is able to vector one or more UAVs to investigate. The manned aircraft provides CPF with an extended communications horizon with the UAV(s), until the hostility of the threat is established.

In the event that a hostile target is detected in this mission, a UAV with an imaging payload offers CPF a capability for real-time target classification, designation and battle damage assessment support, without placing the manned aircraft at risk.

When the target is concealed from CPFs radar systems, likely mission phases are:

1. Surveillance. CPF monitoring passive sensors, including DF and ESM and visual observers; Supporting aircraft monitoring infra-red, radar, ESM, DF sensors, and conducting visual surveillance, as appropriate;
2. Detection: detecting possible targets, with one or more sensors,
3. Classification: estimating probable target type, capabilities and intentions, on the basis of detected signatures, intelligence and/or third-party data;
4. Localization: estimating probable target position, and possibly direction, range, course and/or speed, with uncertainties;
5. Tracking: refining the estimated position, course and speed data, and establishing an estimated state vector for the target, and
6. Engagement: planning and executing an attack against the target, monitoring its effectiveness, and responding, as appropriate, with self-defenses and/or additional hostilities

Throughout the mission, voice and tactical data link communications are also probable, between CPF, supporting aircraft, and/or other cooperating forces.

4.2 ASuW Mission Potential of Various UAV Payloads

Long-range surveillance and engagement of surface targets in the open ocean is obviously very different from close-range coastal patrol operations. The differences in physical and geopolitical environmental assumptions will impose significantly different considerations on the mission system requirements analysis

In the rest of this section, the practical mission value of a selected subset of th possible UAV payloads are explored

The payloads judged to be most useful in support of these CPF ASuW operations are:

1. Imaging Systems, such as:
   a. Forward-Looking Infra-Red (FLIR);
   b. Low-Light TeleVision (LLTV); and
   c. Synthetic-Aperature Radar (SAR);
2. Electronic Support Measures (ESM);
3. Electronic Counter Measures (ECM); and
4. Radio-Frequency Relays (RFR)

A single UAV may be fitted with only one or with combinations of these payloads, according to the relative importance of mission payload performance requirements versus mission vehicle performance requirements.

The larger UAV mission payloads reduce time on station. Some missions, on the other hand, may require a variety of payload capabilities, depending upon how events develop during the mission.

Table 3 indicates in which phase(s), of which mission(s), each payload could be useful.

Payload	ASuW Missions: Long-Range Engagements	ASuW Missions: Coastal Patrols	Mission Phase Code:
FLIR	S,D,C,L,T,E	S,D,C,L,T,E	S=Surveillance D=Detection C=Classification L=Localization T=Tracking E=Engagement TC=Tactical Communications
LLTV	S,D,C,L,T,E	S,D,C,L,T,E	
SAR	S,D,L,T,E	S,D,L,T,E	
ESM	S,D,C,E	S,D,C,E	
ECM	C, E	C, E	
RFR	S,D,C,E,TC	S,D,C,E,TC	

Table 3. Mission Phase/UAV Payload Concordance

The Mission Phase has been mapped into this table, in order to observe the following:

1. The payloads are all useful in the same mission phases of the two vastly different ASuW missions;

2. The same payload equipment may satisfy different tactical mission requirements, according to the manner and the context in which it is employed. Conversely, the same mission phase requirement may be satisfied in a variety of different ways, according to the capabilities of the available payload.

The creative tactical employment of existing payloads in non-traditional ways may sometimes offer an alternative solution to the development of hybrid or multi-function payloads. For example, the Radio Frequency payload (RFR) is more commonly called a communications relay. In this paper the more generic term RFR is deliberately used, to encourage the reader to consider an ESM-like mission application and an ECM-like application (see para 4.2 4)

In the following subsections, we expand further upon the manner in which each type of payload would support these missions

4.2.1 ASuW Mission Employment of UAVs with Imaging Payloads

Imaging payloads offer significant advantages in support of combat ships.

The most obvious advantage is the "bird's eye view" of the surface, which any air vehicle provides. While manned aircraft can also provide this perspective, the UAV approach permits shipboard personnel to make their own interpretation of the situation, eliminating one level of ambiguity from the tactical assessment process. First-hand observation provides the tactical officer with classification and situation assessment data matched by no other sensor subsystem

Real-time video images of a target allow the ship's command to determine threat parameters which are difficult or impossible to discern by other means, such as nationality of flag, deck activity, weapon/sensor system fit and current degree of combat-readiness. During an engagement, LLTV and FLIR imagery will provide indication of fall-of-shot, and inflicted battle damage, as well as detecting enemy weapon firings.

In non-combat scenarios, like peace-keeping and fisheries patrol, a video recording of covertly acquired observations like this can provide invaluable evidence with which to prosecute violators.

FLIR allows the assessment of internal conditions, which would not be apparent on normal TV images.

A SAR offers significant advantages in poor weather conditions. The use of an active sensor is not always tactically desirable, however, and SAR image resolution is typically much lower than FLIR or LLTV. Only major structural damage can be observed. A SAR payload will be most useful in combination with another passive surveillance sensor (such as ESM).

With their relatively small field of view (compared with ESM), and their vulnerability to obstruction by low cloud cover, FLIR and LLTV are better suited to Coastal Patrol support, than Long-Range Engagements, for the Surveillance and Detection phases of the mission. Coastal Patrol search areas will be closer to the host ship, and the area to be searched will be relatively well defined. Long Range engagements will require the UAV to travel long distances, and small uncertainties in defining the search area will result in more lost useful search time.

Effective use of FLIR and LLTV requires areas of uncertain target location of less than 100 sq.nm The UAV is then used to detect, classify, and localize the target to within 500m CEP for a firing solution and BDA.

Table 3, we credit FLIR with being useable when searching for targets which have substantial temperature differential from the environment. Some analysts contend that FLIR is best packaged with another, wide-area, surveillance payload, like ESM or SAR, to facilitate self-cueing of targets to investigate with FLIR, on arrival in the search sector.

NOTE. Some date link bandwidths are insufficient to support real-time video images at high resolutions (see section 4 3), but that does not in itself mean that imaging payloads cannot be exploited with those data links:

- Any single frame image is one more than the ship had before, for classification purposes,

- Slow frame-rates (< 1 frame per second) will suffice for monitoring most surface ship targets;

- The payload itself could capture video at a faster frame rate than the data link would allow, and then transmit images in compressed format and/or in non-real time, if data latency was not a mission-critical parameter;
- The payload could combine several sequential images into a single composite image, either tiled or overlaid, to show changes over a time interval, while transmitting only a single video frame.

4.2.2 ASuW Mission Employment of UAVs with ESM Payloads

Employment of UAV-mounted ESM payloads would provide ships with two advantages:

1. One additional perspective, from each deployed UAV, allowing cross-fixing of brief contacts, and

2. An extended threat surveillance horizon, due to the increased antenna altitude, and the mobility of the UAV.

Knowledge-based systems are already achievable, in which the ESM payload could classify detected emissions according to an onboard threat library, if data link bandwidth were an issue.

Alternatively, pulse descriptor words may be relayed back to the host ship for a centralized analysis. In this approach, multiple independent sensors and operator intelligence could be "fused", to hypothesize the existence and location of particular platforms known to be fitted with the observed emitters

An ESM UAV may prove useful by operating covertly close enough to hostile forces to detect emissions which are beyond CPF's ESM horizon It is also reasonable to suggest that CPF may choose to use the UAV to incite a hostile force into using their radars to investigate and respond to the apparent threat.

This latter strategy suggests that an ESM payload would be useful in combination with an active payload, such as SAR, ECM or even RFR.

A SAR payload would permit searching for "silent" threats, and may incite a curious threat to employ its own radar to investigate the UAV. The ESM payload would then relay back observed data on the radiator(s), to aid in target classification and localization.

An ECM or RFR payload could be used to spoof and jam the threat, to excite a hostile reaction if one was forthcoming, and to confound the target's defence systems, at least partially concealing CPF's HARPOON attack. The ESM payload would relay back information on the target's use of surveillance and fire-control radars and Electronic CounterMeasures, providing CPF with a measure of the imminence of any counter attack.

4.2.3 ASuW Mission Employment of UAVS With ECM Payloads

There is a variety of dissimilar ECM payloads, which could be adapted into UAV systems.

The primary advantage of fitting such payloads to the UAV, as opposed to any other type of platform, is the unique combination of mobility and expendability

Onboard ECM systems are designed to defend the platforms on which they are mounted. Some manned aircraft have actually been cast in the role of manned decoy, interposing themselves between the missile threat and their ships. These aircraft rely upon their own maneuverability and OffBoard ECM systems to protect themselves after decoying the missile away from the ship.

An UAV may be the ideal alternative solution for this mission.

The mission analyst must consider such factors as:

- what degree of onboard payload sophistication is required, according to the number of different missile types to be countered by the same UAV;
- how to provide target detection/designation and tracking support to the ECM function;
- how to coordinate ECM operations in the company of friendly forces;
- how much protection each UAV could reliably provide to which escorted platform(s), by itself, and
- the degree to which ECM UAVs could support each other

A repeater payload would seem to be a particularly useful choice. Particularly in combination with an ESM payload, as suggested in the previous section If illuminated with a radiator, it might confuse hostile threat assessment systems into believing the UAV was another platform of the same type as the illuminator Automated threat analysis systems may be particularly vulnerable to confusion when faced with such behavior

4.2.4 ASuW Mission Employment of UAVs with RFR Payloads

When operating in the capacity of an Outer ASW Screen "picket", CPF will be in excess of 100nm from the screened units. This distance is necessary, partly to remove the Tactical Towed-Array Sonar (TACTAS) sufficiently far away from the noise of the escorted units, and partly to establish a substantial protection perimeter around those units.

It will be particularly problematic for CPF to remain in communication with the rest of the Tactical Force, when on "picket" duty. Their long range and low antenna horizon will preclude intership communications at UHF or VHF frequencies, and the threat of detection and localization will discourage the use of HF.

The need for resolution and low cloud cover may both force a FLIR or LLTV UAV to operate at altitudes below 600 m. At that altitude, CPF would lose contact at ranges between 45 and 70 nm or greater. For that reason, the ship's helo or another UAV may need to serve as a UAV system data link relay

As suggested in Table 3, and in section 4.2.2, above, the RFR payload may also prove quite valuable in the engagement phase of a mission CPF could use the RFR to spoof the target into thinking the UAV was a surface ship or aircraft, emitting the relayed communications. CPF could also employ the RFR to relay back whatever communications it detected. In this mode, the RFR would support Surveillance, Detection, Classification and Engagement phases of missions.

In short, an RFR payload can be used·

1 To extend the Tactical Data Link and voice communications horizon between widely dispersed naval escort units (as alternative to SATCOM or HF communication links);

2 To maintain communications with other UAVs, when their operations force them below the ship-to-UAV communications horizon;

3 To survey the RF spectrum, for channel occupancy detection and reporting, with or without the relaying of intercepted communications to the host platform, for further evaluation; and

4. To issue deceptive and/or corruptive RF message traffic, intended to deny portions of the RF spectrum to the enemy and/or to spoof the enemy's ESM systems.

The RFR payload is also the payload most likely to be compatible with the existing shipboard equipment with which it is designed to interact. This may make integration into the CPF combat system particularly easy.

4.3 UAV System Data Link Issues

4.3.1 General

The Maritime UAV System communication functions must support.

1. A payload data downlink from the in-flignt UAV(s) to the ship's combat system subsystems and workstations capable of exploiting that data; and

2. A bi-directional exchange of mission orders and system status data between the ship and the UAV(s).

The mission orders/systems status datalink(s) must at least support.

1 coordinated control and operation of the payloads of at least two UAVs, one of which may be a UAV datalink relay (to allow operation of imaging payload UAVs at altitudes below 600m, at ranges up to 100nm from the host ship); and

2 simultaneous operation of at least four UAV vehicles

There are at least three options for implementing these Ship-to-UAV-to-Ship datalinks. Any one of them may be dedicated to air vehicle management, and/or incorporate the payload data downlink.

The options are.

1. Fitting a dedicated UAV datalink function to the ship;
2 Retrofitting a UAV control function into one or more existing transceiver subsystem(s); or
3 Exploiting an existing Tactical Data Link

4.3.2 Implementing a Single Dedicated Ship to-UAV Up/Down Data Link

Transmitting real-time high-resolution video images from UAV to ship, at ranges in the order of 100nm places significant demands on the UAV-to-ship payload data downlink.

Once an imaging payload has been integrated into the UAV system, however, the same data distribution and exploitation functions will serve to interpret and distribute the data from any other imaging payload, as long as the image is in the same standard format. This advantage may be subtle, but of all the practical issues involved in the retroactive integration of UAV systems into existing combat systems, this one factor is likely to be the most significant factor, in trade-off analyses.

The most practical datalink option for a UAV system using imaging payload UAVs appears to be a dedicated downlink.

If the system is intended to employ imaging payloads from the beginning, then it may be most appropriate to install a bi-directional link, and to employ the same datalink for UAV mission orders and status reporting.

The advantages of this approach include:

- the ability to implement a communications link optimized to the UAV mission requirements, rather than compromising payload and mission requirements to "fit" the limitations of existing systems;
- the freedom to optimize the design of the UAV-fitted elements of the datalink system;
- the freedom to design a suite of equipment which is independent of specific ship's characteristics, to the maximum extent possible, thus more easily ensuring interoperability of UAVs between different ship classes (and nations);

There are disadvantages also:

- it may not be simple to install a directional transreceiver system, with upwards of 35dB S/N ratio, at C band (one currently favored UAV datalink comms frequency), without compromising existing antenna systems,
- the ship-to-UAV uplink would not need anywhere near the bandwidth of the video payload downlink.

If the intention was to employ non-imaging payloads, (e.g., RFR applications only), then one of the following alternatives may prove more affordable or appropriate. In that case, the subsequent introduction of imaging payloads may only require the addition of a dedicated payload data downlink

4.3.3 Retrofitting UAV Datalink Function into Existing Transceiver Subsystem

The relative merits of this second option over the first one would need to be studied on a case-by-case basis.

If the retrofit were a simple matter of adding a UAV-specific interface to a system of otherwise similar function, then there may be significant advantages to this approach.

If the UAV itself was likely to only ever operate with one particular payload, and that payload would normally interface with an existing shipboard control/data link, then this strategy would be the best choice. In addition to exploiting existing equipments, such a scenario would likely find that the UAV payload operator would be the usual operator of the sensor subsystem with which the payload was communicating. (An example of this might be a communications relay payload).

It is unlikely, however, that this strategy would always serve equally well for both UAV vehicle control and payload control, since payload control is not traditionally the province of the air vehicle controller.

The distributed architecture of the CPF SHINPADS is particularly advantageous, in this respect. The payload and air vehicle control functions may be implemented at any combination of consoles and still be collected and coordinated through a single retrofitted UAV system datalink processor, added onto the databus.

Some analysts may consider evaluating the use of existing systems like AN/SLQ-32, JTIDS, IFF, and LAMPS, to integrate UAVs into existing tactical control and data analysis and exchange networks. If other countries eventually choose to proceed this way, a dedicated UAV datalink may be the only way for CPF to achieve interoperability with those UAVs (i.e.: by emulating the chosen datalink(s)) (Interoperability of UAVs is one of the Maritime UAV System performance objectives of NATO PG-35).

4.3.4 Exploiting An Existing Tactical Data Link

Any combat system already designed to control aircraft is likely to include a dedicated operator (such as the Anti-Submarine Aircraft Controller (ASAC), on CPF), already trained in air traffic control and safety. He would already have control over the functions by

which to exchange air vehicle navigation and mission control orders and status messages with Tactical Link capable platforms.

Minimal special hardware or software additions would need to be made to existing ships' combat systems, to support this type of interface. Control of vehicle and payload could be handed-over between existing NATO platforms compatible with the same Tactical Data Link specifications

A single UAV could simultaneously support all platforms on the same Tactical Data Link network

The "downsides" to this approach are that.

- the Tactical Data Link messages tend to be inadequate to transmit the wealth of sensor payload data which could otherwise be relayed for shipboard processing (this is particularly true with imaging payloads),
- weight and security issues may preclude this option when Crypto devices are used on the Tactical Data Link, and
- if the UAV recovery phase required close control, then it would probably be unacceptable to have use of the communications link limited by polling sequence There may also be a practical problem of line-of-sight masking, between the Tactical Data Link antenna and the flight deck

Some analysts are investigating the adaptability of Link 16 (JTIDS) to this application CPF is fitted only with Link 14 and 11, neither of which appears adaptable to video image transmission.

4.4 UAV System Management

4.4.1 Mission Planning and Direction

UAV Systems will be managed by the ship's combat system crew UAVs will be dispatched on missions, as would any other controlled air asset In order to employ UAVs, the shipboard element of the UAV System will require mission planning, situation monitoring and in-process mission modification functions.

The mission planning functions will be at least partially present on CPF, all the more so once the NSA Shipboard Tactical Support System (STSS) has been integrated. The UAV is designed to be programmed, via the ship-to-UAV data uplink An umbilical link provides for pre-launch transfer of mission orders to the vehicle, under EMCON silent conditions.

Situation monitoring and in-flight re-programming of air vehicle and/or payload performance will be implemented by incorporating a bi-directional communication link between the combat system and the UAV.

Control of the payload and of the air vehicle will be exercised by the appropriate ship's combat system personnel The air vehicle itself will most likely be managed by the ASAC. The payload management requirements need study The specific manner in which these functions should be implemented on CPF would be driven by the nature and the sophistication of the UAV exploitation capability requirements

4.4.2 Payload Data Exploitation

The mission value of a UAV payload is directly proportional to the ability of the shipboard combat system to "exploit" that data.

4.4.2.1 Payload Management

Each type of payload in section 4.2 exhibits characteristics which necessitates payload management messages unique to those characteristics. Full exploitation of individual payloads of the same type, may further necessitate specific modifications to the messages by which each payload variant is managed

As mentioned in section 4 3.2, however, the data exploitation functions which support management of imaging payloads are likely to have a high degree of commonality. Even non-imaging payloads (such as ESM) can be programmed to format and transmit a video page, in lieu of discrete messages While this may seem inefficient, it may provide a solution to interoperability of UAVs with payloads not generally possessed by all forces, without the necessity to modify each ship's payload data management functions to exploit those payloads

It is generally accepted that exploiting the data from an imaging payload requires at least the following functions

1. a video display annotation function;
2. a freeze (video) frame function;
3. a video display rotation function;
4. an image magnification /minimization function,
5. a range distortion correction function,
6. a video recording function,
7. a recorded video playback function

Where, in the Maritime UAV System, these individual functions are implemented will have significant bearing on the component and the interface design and integration tradeoffs.

A dedicated Maritime UAV console may be able to provide all the functions itself, but in some applications the need for a dedicated console may be an unacceptable operational constraint.

Various existing ship's combat system consoles may provide all, some or none of these functions, in different ways. Solutions which minimize impact to existing systems may present an obstacle to the development of a "universal" Maritime UAV System.

In some cases, the specific mission requirements of different customers may dictate different optimal approaches to the same function. (eg: For some applications, image magnification may be best done by modifying the focal length of the lens on the payload, in real time. This may create a unique requirement for the associated control and status messages on the datalink. For other applications, image magnification must be performed on the historical image, mandating extremely high real-time image resolutions, video compression techniques, and high downlink data rates.)

4.4.2.2 Routing UAV Payload Data to Combat System Console Operators

The CPF combat system architecture offers at least 3 ways of distributing UAV payload data to the existing operator consoles.

1. Video Data Distribution: whether the payload data is visual imagery, or whether the data has been formatted into a video image, once the data has been downlinked and converted into an RS343 or RS170 video signal, it can be selected to any combination of the Standard Display consoles, via the CPF Video Distribution Unit.

2. Tactical Data Link Data Distribution: if the UAV is able to operate on a Tactical Data Link, then it can function as a Reporting Unit (RU). All tactical data messages would then be processed and distributed through the existing Data Link processing functions.

3. The CPFs (SHINPADS') distributed combat system architecture also permits the easy addition of new sensor subsystems onto the command and control system serial databus. Once the new subsystem is on the bus, it is straightforward to program a message-handling interface software module, to recognize, process and route the new message traffic. UAV sensor data reports would need to be referenced from the UAV position, rather than from ownship's position, through. This could be done by modifying the tactical database, to create data stores for UAV sensor reports, or by routing the messages to the Link 11 processing software as if it had been received via Link 11 from a UAV functioning as an RU.

4.4.2.3 Fusing UAV Payload Data In the Ship's Combat System

As with all information management systems, the volume of data which a field of multi-sensor UAVs will be able to acquire will rapidly exceed the capacity of existing combat systems to assimilate. The problem will not be UAV payload data link bandwidth, so much as Combat System information processing throughput.

One technology which offers a potential solution to this information management problem is Multi-Sensor Data Fusion.

At its simplest, UAV data may be "fused" with existing combat system data by simultaneously displaying the video imagery derived from them both. (e.g: displaying a FLIR image of a target in a "window", on the same display as the ship's own radar image and tactical (NTDS symbol) plot).

More complex data fusion systems may cross-correlate UAV, Ownship, Tactical Data Link, and threat library data, to achieve any combination of the following:

- contact classification, by cross-correlation of platform signature data with known threat characteristics;
- inference of contact presence and/or intentions, by cross-correlation of sensor subsystem signals and "noise", from dissimilar sensors; and
- target localization and tracking, by cross-correlation and filtering of independently located passive sensor subsystems

Knowledge-based image recognition systems could be programmed to "recognize" targets, according to unique signature data as vague as their silhouette or as specific as their hull-numbers.

Payloads could be programmed to transmit video images containing specific preprogrammed events (e.g., missile launch events, might be detectable as a sudden increase in UV and IR spectral content)

With the successful implementation of

reliable multi-sensor data fusion systems, the introduction of multi-vehicle UAV systems in support of future naval forces may become as routine as the deployment of sonobuoys.

A widely distributed field of dissimilar sensors will provide a single ship's combat system with simultaneous statistically independent measurements of spectrally-independent signature characteristics in a significantly larger area than it is able to monitor with ship-mounted sensors alone.

5. Conclusion

Exercises like JANTIDE and MAVUS confirm the viability of CL-227 Sea Sentinel System mission Roles and Tactics in support of Maritime Forces.

The CPF is Canada's latest warship, similar in configuration and mission to missile carrying frigate in the MAVUS exercise, but with the added advantage of a C^2 system which uses the SHINPADS open architecture

Integrating a Maritime UAV system into the CPF Combat system offers at least the following significant enhancements to her already impressive capabilities:

1. A low cost complement to manned aircraft deployment, in support of OTH missions, such as Over The Horizon Targeting, Battle Damage Assessment and Naval Gun Support.
2. A Stand-off ECM capability
3. Tactical options which would be unacceptably risky with manned vehicles, such as deliberately provoking responses from suspected hostiles.
4. The ability to simultaneously operate multiple airborne surveillance vehicles, off a frigate designed to host one helicopter.
5. An organic aerial surveillance capability, even when the helicopter air detachment is not embarked.
6. A low cost airborne communications relay, to maintain UHF contact between widely dispersed units

As data fusion processes automatic target detection software and expert systems technologies mature, multiple vehicle UAV systems will become common extensions to surface surveillance and targeting systems.

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DISCUSSION

DISCUSSOR: **Col. CORBISIER** (Belgium)
(NU). To what extent are flight operations restricted by adverse weather ?

AUTHOR'S REPLY :
(NU).
- Simulation confirms feasability of automatic Take-off and Landing in, at least sea-state condition 5.
- Flights have been carried out in 40Kt winds with high gusts (wind shear warning in effect).
- Flights have been carried out in light rain and light snow.
- Full envelope remains to be defined ; particuliary icing conditions.
- To date, sea operations : Point Mugu, California ; Pax River Land-Montreal ; Alberta Canada ; Yuma ; Fort Huachuca ; and Washington State/USA.

AN INTEGRATED MULTIPLE-SENSOR FIRE CONTROL SYSTEM FOR AIR-TO-AIR COMBAT

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1. SUMMARY

This paper describes a system including integrated fire control algorithms, software, and related control and display concepts for air-to-air combat in the multiple-target environment of the 1990's. This system, now completing advanced development, fuses data from multiple sensors and presents integrated fire control information to the pilot in a simplified manner for improved situation awareness and decreased workload. The resulting algorithms, software, and display concepts are described in this paper. The system has been demonstrated and evaluated on a flight simulator with Air Force pilots. The fire control software, which was developed in the Ada language, was implemented in a distributed data processing complex of the PAVE PILLAR type, using MIL-STD-1750A processors. The sensors and data links, as well as the aircraft and its environment, were simulated by mathematical models.

2. INTRODUCTION

In the air combat environment of the 1990's, an air-to-air fighter will need improved multiple-target engagement capability compared to current aircraft. One of the required improvements is a fire control system with improved capability to aid the pilot in attacking multiple targets. This paper describes an integrated fire control system using improved computers, sensors, and an intraflight data link which are expected to be available in the 1990's. The purpose of the system is to provide the pilot with easily understood attack management information, while leaving major decisions in his hands. Computers with the necessary storage and throughput capacity are available now. The improved sensors, particularly an electronically scanned array (ESA) radar for multiple target tracking, and an intraflight data link capable of high-data-rate transfer of information between aircraft operating at mutual-support range, are expected to be available in the 1990's. The algorithms, software, and control and display concepts developed in this program are to be implemented on such equipment to provide the pilot with easily-understood attack management information with reduced workload.

3. SYSTEM DESCRIPTION

The avionic system for which the software and pilot/vehicle interface concepts were developed is shown in Figure 1. It is intended to be for a representative single-place air-to-air fighter of the 1990's, armed with medium-range radar-guided missiles, short-range infrared-guided missiles, and a gun. The sensors and data links used in the system were represented by mathematical models in the flight simulator. The ESA radar has a phased-array antenna in which the direction of the transmitting and receiving beam can be controlled instantaneously by controlling the phase shift of the many individual elements of the antenna. The computer software for phase control of the elements and for radar signal processing is considered to be included in the radar, and was not developed as part of the attack management software. The infrared search and track (IRST) set is assumed to have a mechanically scanned gimbal; it can measure the angular direction and intensity of a source of infrared radiation. The passive sensors detect and measure angular direction and identification of radio-frequency sources. The Identify Friend or Foe (IFF) set can interrogate a target and determine whether it gives a response identifying it as friendly. The wide-area data link, as simulated in this system, provides wide-area communication of battle management data to friendly aircraft at a low data rate (once every ten seconds). Because of this low data rate, there were limitations on how completely wide-area data could be combined (fused) with on-board sensor data. A separate intraflight data link is assumed to communicate data between aircraft of the same flight with a much higher data rate than the wide-area data link, but with a shorter maximum range.

The attack management software, developed in the Ada language, was implemented in the mission data processor complex, using a distributed processing architecture of the type developed in the PAVE PILLAR program. Five MIL-STD-1750A (16-bit) processors were connected to each other and to a random-access memory by a high-speed data bus. The requirement for five processors was determined by throughput requirements; each processor had a throughput capacity of 1.7 mega instructions per second (MIPS). The software architecture avoided use of the parallel tasking feature of Ada, which was considered to be a possible source of trouble. Instead, parallel operation of independent, separately-compiled parts of the software ("logical processors") was controlled by an Ada-based executive program working through an operating system of the PAVE PILLAR type. The executive program is described in Reference 1. The operation of the mission data processor complex depended on the connection of the processors to a common data base in the random access memory hrough a parallel data bus with a capacity of ten megawords

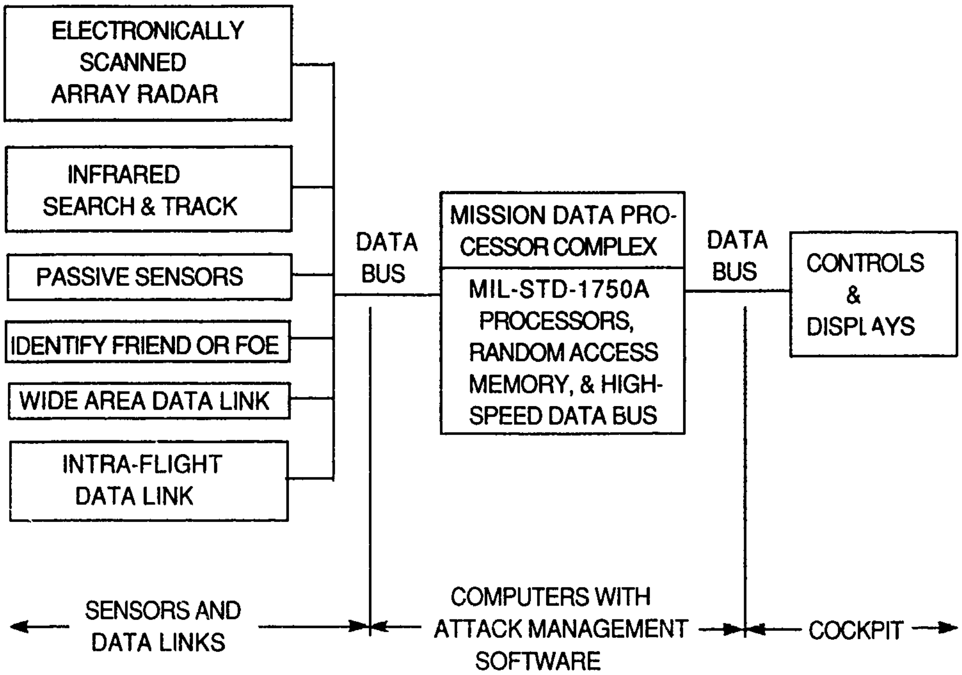

Figure 1. Avionic System for Air-to-Air Attack Management

per second. The random-access memory had a capacity of 256K (where K=1024) 16-bit words. The total size of the attack management source software is approximately 20,000 lines of Ada. This software also has been adapted to a single 32-bit computer with a throughput capacity of 5 MIPS for another Wright Laboratory program (Reference 2), which is to include flight test. The flow of data in the system is illustrated in Figure 2. The sensors provide track files, consisting of target location and identification data, to the attack management portion of the system. The attack management software performs four main functions, which are described below: Sensor Control, Multisource Integration, Internetting, and Fire-Control Decision Aids.

3.1 Sensor Control Function
The Sensor Control automatically commands all of the controllable sensors shown in Figure 1, subject to conditions set by the pilot. The commands it gives to the sensors include sensor modes, areas to be searched, targets to be tracked, and requests to provide identification data. The pilot selects the overall search area and the emission mode; active, passive, or low-probability-of-intercept. The Sensor Control allocates sensor resources to search and track targets based on an intelligent prioritization algorithm. This prioritization algorithm allows the Sensor Control to react to the changing tactical situation. The Sensor Control is partitioned into five functions. The first function, switchboard operations, determines which sensors are available, and for each available sensor it determines which active tracks it can service. The second function, search area definition, computes individual sensor search areas. The third function, track file prioritization, prioritizes all possible track services that can be provided for each serviceable MSI track. The three types of track services available are track update, track identification, and track raid assessment. The highest priority is given to targets towards which missiles are in flight, and targets which are next in priority for a missile launch. The fourth function, sensor load allocation, determines the sensor services to be performed by each controllable sensor. A selection process is used to determine the best sensor to perform a given service. The last function, sensor director, is responsible for reformatting the sensor commands in a form acceptable for output for each controllable sensor. A more complete description of the Sensor Control algorithms is given in Reference 3.

3.2 Multisource Integration (MSI) Function
The MSI function combines ("fuses") target tracking and identification data from sensors on board the aircraft, to cope with multiple maneuvering targets. The MSI algorithm, as implemented in this system, takes advantage of the complementary characteristics of each sensor, making full use of its desirable features, while de-emphasizing its relative weaknesses. The analytical vehicle for sensor fusion in this system is the Kalman filter. The

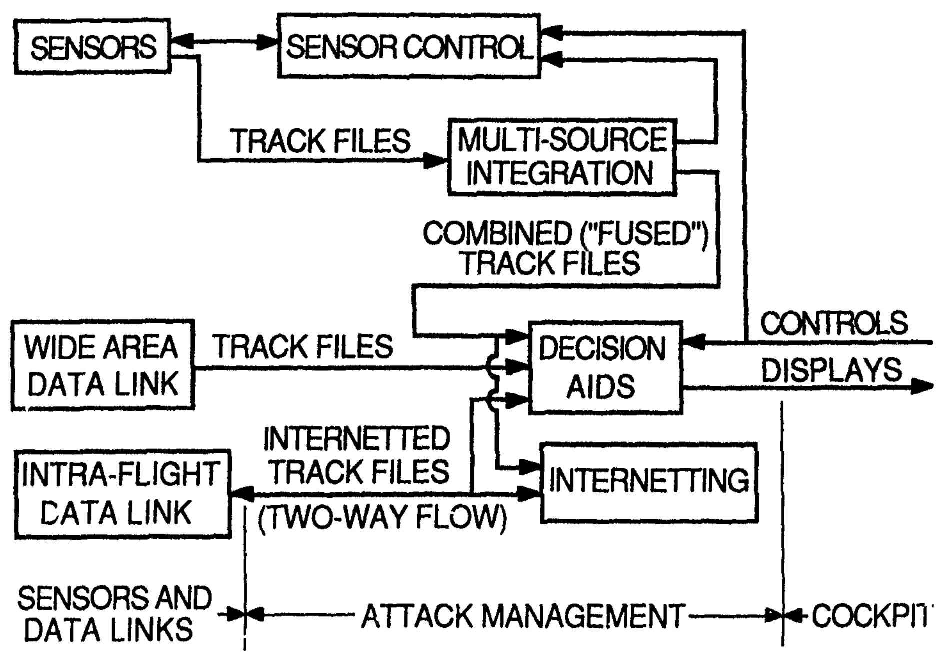

Figure 2. Data Flow in Attack Management

range/range-rate measurements are decoupled from the angle measurements in the implementation. Consequently, if a particular sensor report has angle data only, it can be processed in the usual way, and the MSI track vector can be updated with angle-only measurements on that particular frame. In order to track maneuvering targets, the Singer algorithm is incorporated into the Kalman filter, using an augmented state vector that contains acceleration states. The resulting MSI track files contain fused target location and identification data from all sensors on board the aircraft.

The MSI function utilizes three subfunctions. The first subfunction is track file maintenance. This is a central-level kinematic fusion algorithm that receives inputs from various sensors and sequentially fuses them into a track file. Critical algorithms developed for this subfunction include sensor track propagation, MSI track propagation, and MSI correlation. The second subfunction is identification assessment. The identification of an aircraft is determined by fusing all the identification data available on an MSI track. The third subfunction is sensor utility assessment. This estimates the ability of the sensor to update an existing MSI track based on a record of its past performance against active MSI tracks. For each on-board tracking sensor, a running probability is maintained of its chances of success in updating the MSI track. This information is used by the sensor manager in determining the allocation of sensors to tracks.

3.3 Internetting Function

The internetting function fuses MSI track files and attack data with data from other friendly aircraft connected ("internetted") by an intraflight data link, and supplies the output necessary to provide each aircraft with the same picture of the battle environment. This output includes the internetted track file (ITF) package from which each aircraft can generate a common tactical situation display. The intraflight data link concept is based on a token-passing protocol. The aircraft which possesses the token updates the internetted track files with data from its own MSI track files, then broadcasts the updates to all other members of the cooperative force. The internetted track files are maintained in rectangular Cartesian coordinates referenced to a common grid. The three major internetting functions are internetted track file maintenance, cooperative attack planning, and data link controller. The internetted track file maintenance creates internetted track files by combining ownship MSI files with the existing track files, and provides passive ranging capability between two or more aircraft from passive sensor angular data. The cooperative attack planning performs attribute integration, computation of threat missile launch envelopes, and cooperative prioritization of the targets. The data link controller provides the

interface for information transmitted to and received from internetted aircraft over the data link.

3.4 Fire Control Decision Aid Function
The purpose of the this function is to compute fire control information for display to the pilot for performing a successful attack. The information to be displayed is computed from the internetted data and the MSI data, with the pilot providing inputs which control the type of information computed and displayed. Suggestions are provided to the pilot on which target to engage, which weapon to use, how to approach the target, when to fire the weapon, and the outcome of the weapon/target engagement. The decision aids displayed to the pilot were described in a previous paper (Reference 4). There are six major decision aid subfunctions. The first, autonomous prioritization, provides a suggested order of engagement and a weapon allocation. The prioritization and allocation are presented to the pilot and an override capability is provided. Some of the criteria used to determine prioritization are relative geometry, position within the threat missile launch envelope, first-shot probability, and target type. The second subfunction, attack steering, provides steering cues to the pilot appropriate to the particular weapon to be deployed. Azimuth and elevation cues are provided for collision steering based on ownship and missile speeds and the relative position and velocity of the target. The third and fourth subfunctions are the missile launch envelopes (MLE) for the medium and short-range missiles. The purpose of the MLE is to indicate to the pilot the effective launch range of the missile and when acceptable launch conditions are met. The fifth subfunction, gun steering, provides visual cues to the pilot for firing the gun. It provides azimuth and elevation steering, maximum range, and a break-off cue when disengaging is advisable. The last subfunction, kill assessment, provides the pilot with information on the outcome of a missile launched against a target. It computes whether the missile could have reached the target, and uses sensor data to determine whether a kill has occurred based on kill indications, including radar and infrared signatures and sensor-observed kinematics. The controls and displays used by the pilot in the cockpit to interface with the fire control decision aids will now be described.

4. COCKPIT CONTROLS AND DISPLAYS

The type of cockpit for which the control and display concepts were designed is shown in Figure 3. The head-up display at the top displays attack information superposed on the view out the windshield. Although flight information such as speed, altitude, and attitude is available on the electronic displays, backup flight instruments are provided for flight safety reasons. The special-purpose alphanumeric display shows the status of the communication and data links. The instrument panel also has a master arm switch and switches to control the mode of operation of the sensor control software; with them the pilot chooses active, passive, or low-probability-of-intercept operation of sensors such as the radar. The three multi-function colour displays have pushbutton switches in the bezels surrounding them, for selecting various display formats and otherwise interacting with the system. The pilot can activate these buttons either by pressing them

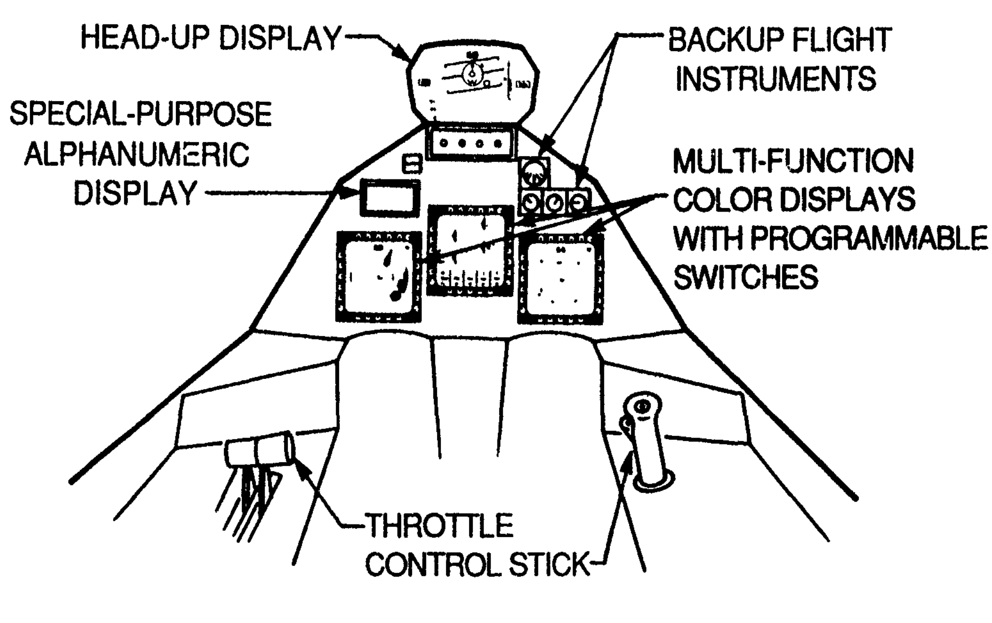

Figure 3. Typical Cockpit for Air-to-Air Attack Management

manually or by using the target designation switches on the throttle.

Figure 4 illustrates the switches on the throttle. The view in the figure is of the forward and right sides of the throttle, where the switches are located. The Target Designator Control (TDC) is used to control the motion of a cursor used to select a target symbol or bezel switch on a display. When the cursor has been placed at the position of the target or the switch, pressing the Designate switch designates the target or activates the switch. A target designated by the pilot becomes the number one (highest) priority target, superseding any target priority determined by the fire-control decision aids. The Cage/Uncage switch controls caging of the target seeker of the short-range infrared missile. The Chaff/Flare switch controls manual release of chaff and flares.

Figure 5 illustrates the switches on the control stick. The Sensor Control switch controls the sensor search displays for ownship or for selecting the Close Look display format, as well as controlling access to the boresight and vertical acquisition (VACQ) Air Combat Maneuvering

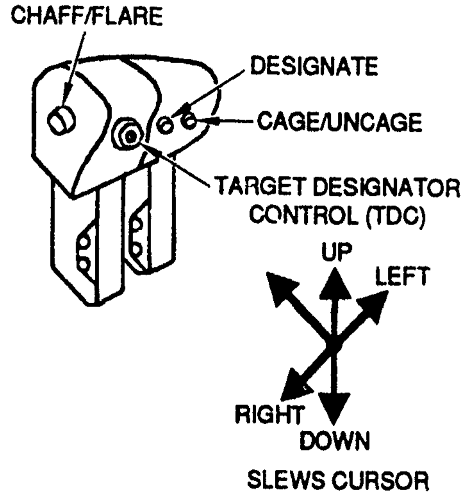

Figure 4. Throttle Switches

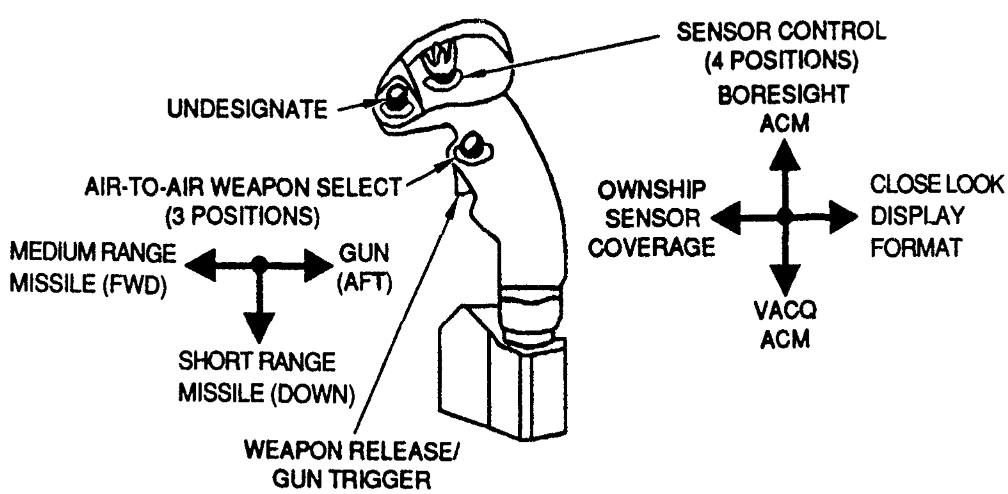

Figure 5. Control Stick Switches

(ACM) sensor modes. The Undesignate switch is used to remove the designation of a target as number one priority, for example, after a missile has been launched at that target and the pilot does not want to launch a second missile at the same target. It is also used to leave the ACM sensor modes. The Weapon Release/Gun Trigger launches a missile or fires the gun at the number one priority target. Whether the gun is fired or a missile is launched, and the type of missile launched, are determined by the position of the Air-to-Air Weapon Select switch at the time the Weapon Release/Gun Trigger is depressed.

Note that the system provides for all major decisions to be made by the pilot. The weapon fired is always determined by the position of the Air-to-Air Weapon Select Switch, as selected by the pilot. The weapon is fired or launched only when the pilot presses the Weapon Release/Gun Trigger. The target at which the weapon is launched is always the target designated manually by the pilot, if he has selected one. If he has not designated a target manually before he presses the Weapon Release/Gun Trigger, the selected weapon is fired at the highest priority target, as computed by the system and displayed to the pilot. The pilot keeps control by not firing until the highest-priority target on the display is the one he wishes to shoot.

The symbols displayed on the Head-up Display (HUD) were developed by modifying those used in present-day aircraft. Figure 6 shows the display used when the medium-range missile has been selected. The scales on the left, top, and right show airspeed, heading, and altitude, respectively. The vertical scale to the left of the altitude scale displays maximum, minimum, and no-escape missile launch ranges for the two highest-priority targets, with the highest priority target being on the left side of the line. The carets (<) with the numbers inside show the present target ranges and closing speeds. The squares are target designator boxes showing the locations of the two highest-priority targets. The asterisk (*) marks the highest-priority target, which is the one at which a missile will be launched when the pilot presses the Weapon Release switch. In the center of the display are a steering dot and an allowable error circle for steering toward the highest-priority target. In the upper right are the numbers of medium and short-range missiles remaining on board. If the system recommends the use of a different missile type than the one selected by the pilot, it indicates this by an arrow pointing to the recommended missile type. In the lower right are the time until the missile seeker is active and the time until intercept for the most recently fired missiles. The numbers in the lower left corner are the Mach number and acceleration (in g's) of the aircraft.

Several different display formats can be displayed on the head-down Multi-Function Colour Display (MFCD's).

- Situation format
- Tactical Planning format
- Close-Look format (with optional variations)
- Threat format
- System Status format
- Search Volume format
- Identification Confidence format

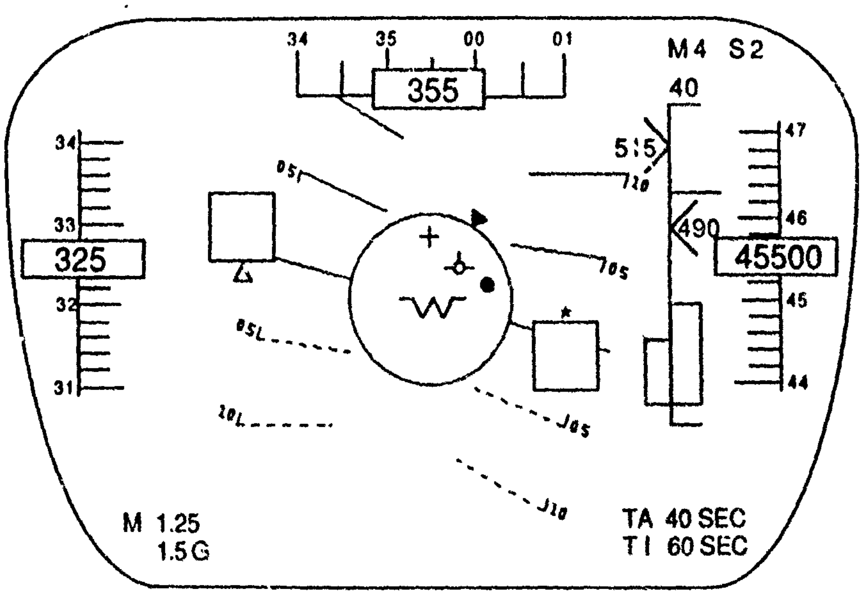

Figure 6. HUD Medium Range Missile Format

Since the three MFCD's in the cockpit are of equal size, it is possible to put any display format in any of the three display locations. The situation format is important enough to be displayed at all times on one location. The pilot is given the choice of the Tactical Planning or Close-Look format in a second location. He can choose any of the remaining four formats for the third location. In the flight simulations, the Situation Format was located on the right display, with the Tactical Planning and Close-Look formats in the center, as described in Reference 4.

The Situation Format shows fused location and identification information on all aircraft for which data are available, as well as navigation and other data. Figure 7 shows an example of a Situation format display. The scale of the display can be changed by switches on the bezel. Other switches allow the pilot to select the amount of detail displayed; eliminating some displayed data makes the display less cluttered. Some of the optional items are:

target identification
target altitude and speed
planned route, corridor, and waypoints
hostile surface-to-air missile sites

Target symbols used on the displays are defined in Figure 8. The symbols are either outlines or filled in (solid), depending on the source of the target data. When the pilot has pressed the button marked "SELF", only the targets tracked by ownship sensors are filled in. Otherwise, all targets tracked by aircraft on the intraflight data link are filled in, and only wide-area data link targets are shown as outlines. These features help the pilot to decide whether the target track is accurate enough for launching a missile.

The basic Tactical Planning Format is similar to the Situation format, but has some different display options available, such as missile launch ranges. On it the pilot can request a Close-Look display of the area around the target designated by the close-look symbol. The Close-Look format can display recommended target priorities and other data requested by the pilot. Examples of Tactical Planning, Close-Look, and Situation format displays were shown and discussed in Reference 4 for a representative engagement.

The Threat format is displayed in the remaining display location when no other format has been selected. An example of a Threat format is shown in Figure 9. This

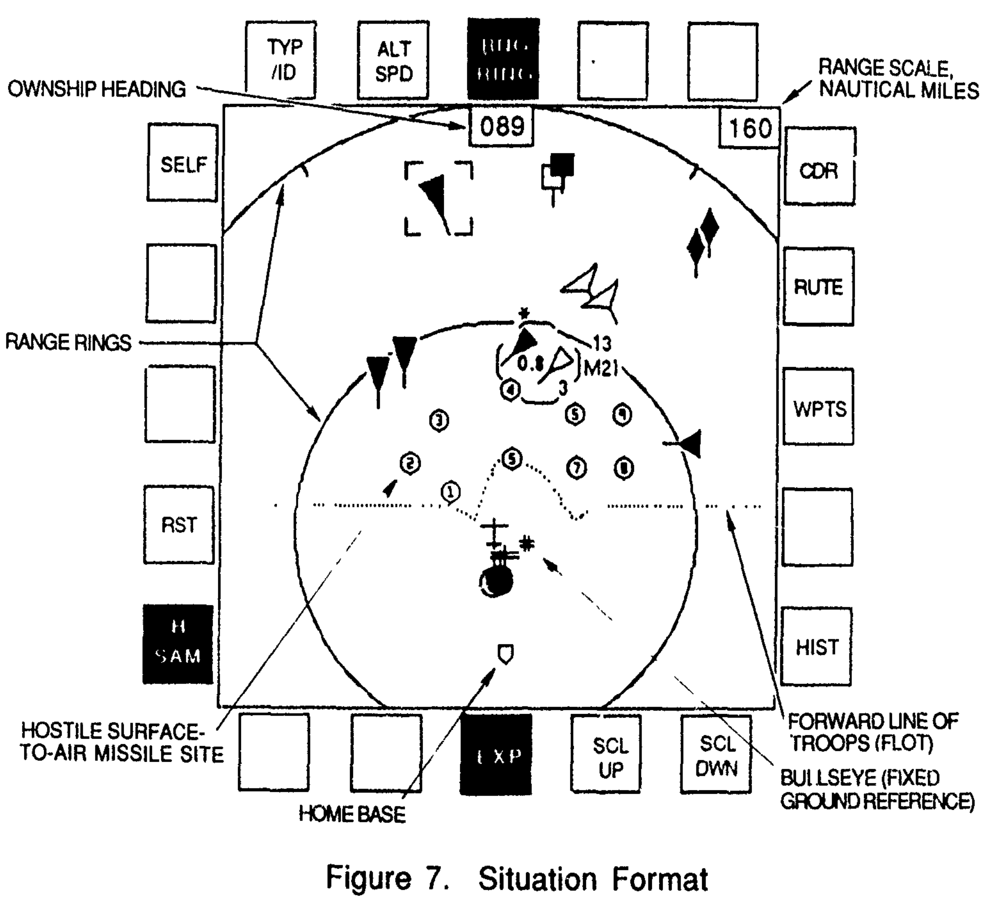

Figure 7. Situation Format

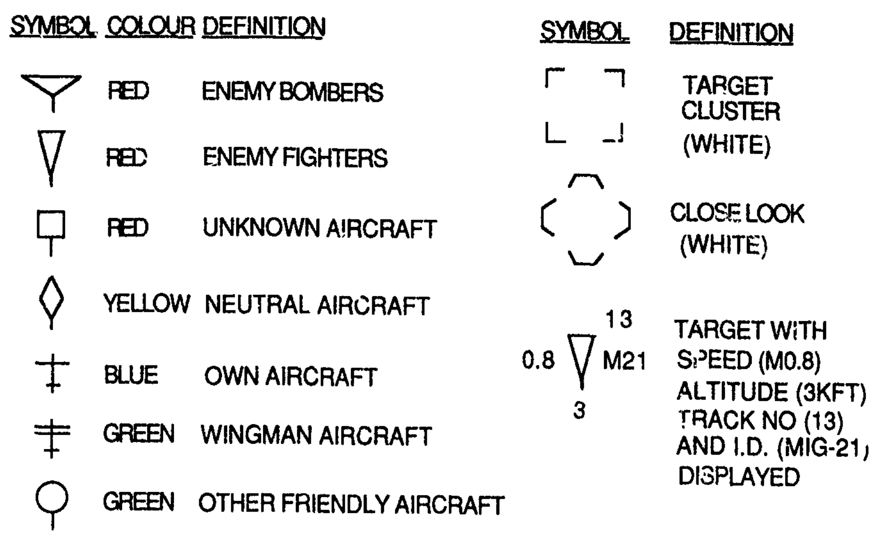

Figure 8. Target Symbols

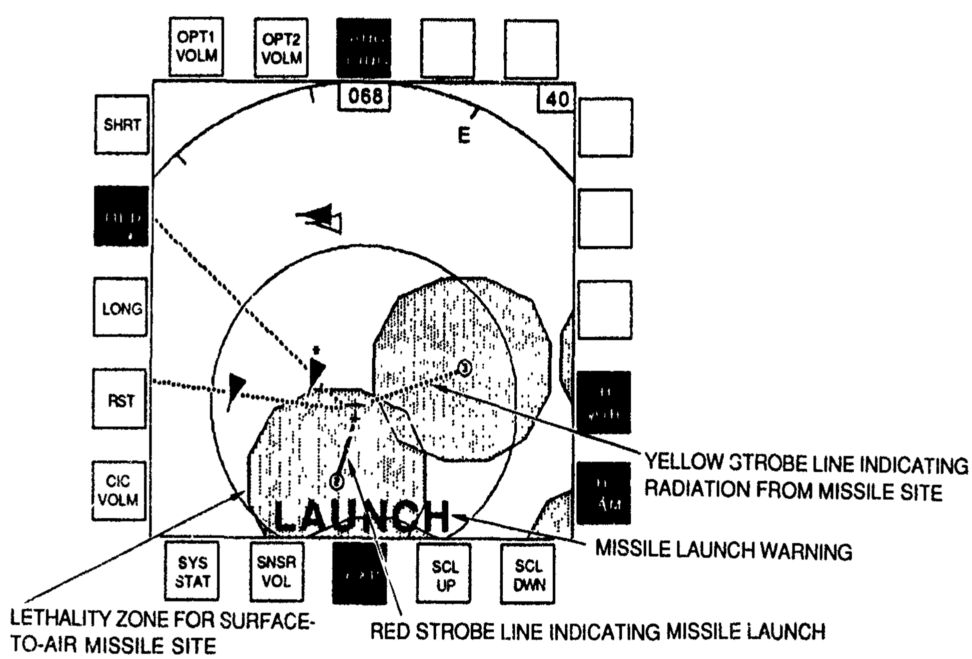

Figure 9. Threat Format

is a plan view on which the location of hostile aircraft and hostile surface-to-air missile (SAM) sites are displayed, together with indications of jamming and hostile SAM and air-to-air missile launches. Pushbuttons on the bezel are used to display the Search Volume and System Status formats and to control the sensor search area. On the Search Volume and System Status displays, the pilot can select a display of information for his own aircraft, or for other aircraft internetted by the intraflight data link. An example of a System Status format is shown in

Figure 10. It is a pictorial display of the status of fuel, thrust, weapons, jammers, chaff, and flares. An example of a Search Volume format is shown in Figure 11. The lower part of the display is a plan view, and the upper part is an elevation view, altitude vs. range. The pilot can display the search volumes for other aircraft in his flight, but he cannot change them with his controls. The capability could have been put into the system, but the pilots felt strongly that it would create undesirable confusion. The Identification Confidence format is not shown here, since it is expected to be used only in special cases. The pilot can request it if he wants to see details of sources of the target identification data used in a Close-Look format option.

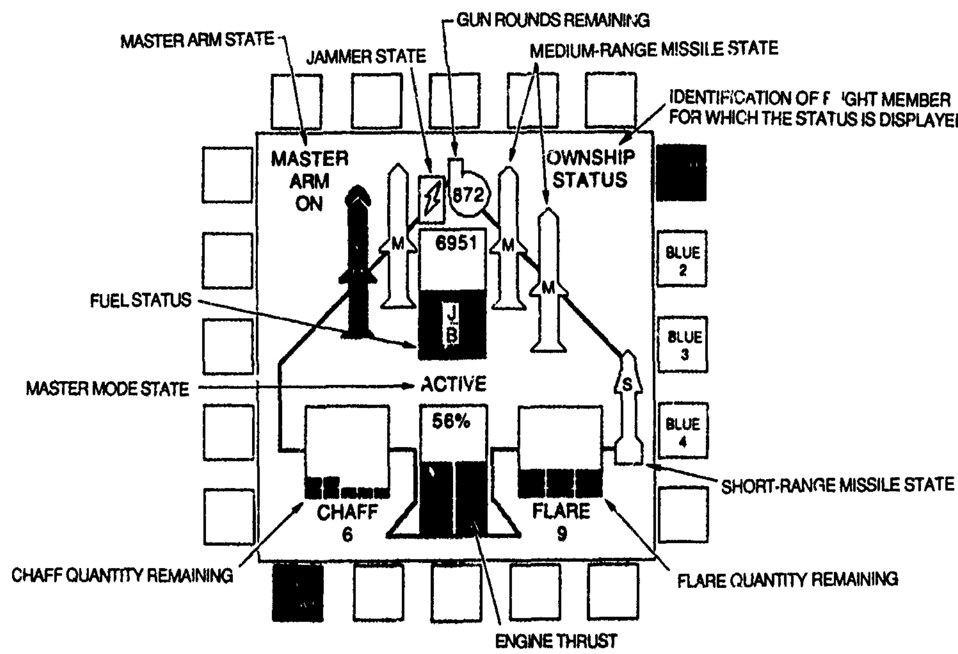

Figure 10. System Status Format

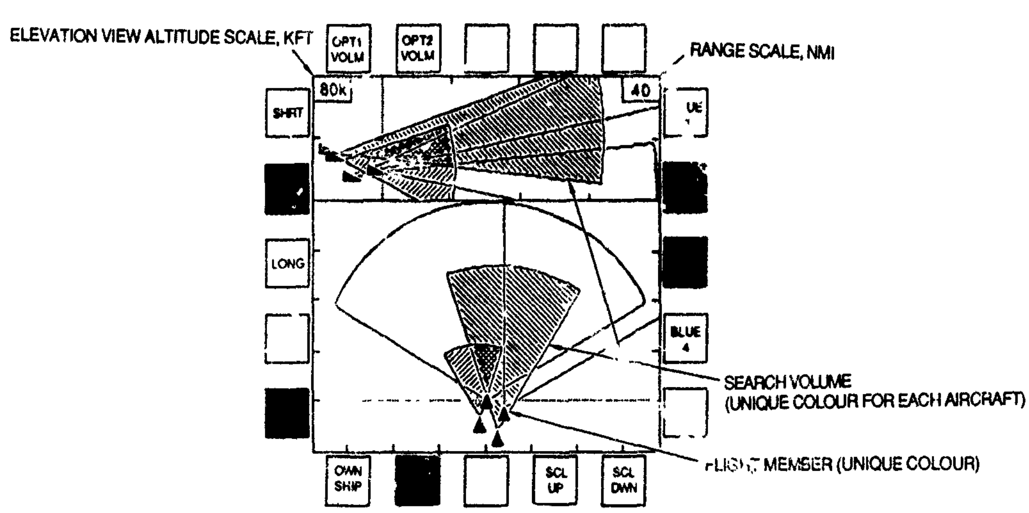

Figure 11. Search Volume Format

5. INTEGRATION AND TEST

The software for the mission data processors was developed in the Ada language. Parts of the code were developed by subcontractors; the Boeing Military Airplane Company developed the pilot/vehicle interface (control and display) software, and the TAU Corporation developed the Sensor Control software. The subcontractors used the same model of VAX computer and compiler as the prime contractor, the Northrop Corporation. The top-down design provided for the modular distributed data processing to be controlled through a common data base. Early definition and control of the common data base were necessary to coordinate the software design. Integration of the software was performed in Northrop's Avionic Integration Laboratory (AIL). The first steps in integration used the VAX computer and the VAX Ada compiler. An emulator was used to represent the effects of the distributed processing operating system. Then the software was recompiled and hosted on the MIL-STD-1750A computers in the mission data processor complex. Integration was continued in the AIL with the mission data processor complex connected to an Encore computer of the same type used in the flight simulator. As in the flight simulator laboratory, the Encore computer included mathematical models of the sensors and other simulation variables, for more complete real-time integration testing than was possible on the VAX computer.

The final integration and test were performed in Northrop's flight simulator laboratory. This laboratory uses a complex of Encore Concept 32/9780 computers and Floating Point System array processors to implement mathematical models of the sensors, aircraft, weapons, targets, and geometry. The same mission data processor computer complex hardware and software used in the AIL were used in the flight simulator laboratory. Two manned Interactive Control Stations (MICS) were used for the cockpit controls and displays, each with its own mission data processor complex, control stick, throttle, and with the displays represented on a Silicon Graphics, Inc. display processor. The pilots considered the limited visual realism of the display to be satisfactory for the conditions used, in which the most significant action was beyond visual range. After the first flight simulator evaluation period, these friendly ("blue") control stations (MICS) could be replaced by two MICS which represented an avionics system without the attack management system, for comparison of results to evaluate the effects of the attack management system. The enemy ("red") aircraft in the simulation were a mixture of MICS (manned) and computer-simulated ("digital") targets. The digital targets were simulated by computer programs using logic representing fighter aircraft tactics.

The first demonstration and evaluation on the flight simulator was in May 1990. The evaluation period was two weeks, following four days of pilot training in operation of the system. Three teams of two pilots each took turns manning the two blue stations, with the red aircraft being six computer-simulated targets. The pilots were U. S. Air Force captains with air-to-air experience in the Tactical Air Command. The system was evaluated as having a very great potential, but needing some corrections and improvements in the software, controls, and displays. Another evaluation on the flight simulator was performed in August 1991, after the algorithms and control and display concepts were modified for greater pilot acceptance.

Evaluation of the system was broken down into six categories. The first category, top-level measures of performance (MOP) and measures of effectiveness (MOE), focused on the performance of the system during the simulation. Specific MOP's and MOE's are listed in Figure 12. The second category concerned the performance of individual algorithms or combination of algorithms within the system. Specific tests that were performed are listed in Figure 13. The third category, tracking loop analysis, focused on single-ship tracking performance. Specific tests include measuring the contributions of the various sensors to tracking and identification, effects on tracking performance of being in the low-probability-of-intercept or passive modes, and measuring the MSI and internetted track filter covariances over time. The fourth category, internetting, was concerned with the performance of the internetting data link. The measures employed were the percent of time spent in the data link and the token rate as a function of the number of tracks. Join/rejoin characteristics were also characterized by measuring such parameters as the number of tracks passed over the link during rejoin, the amount of time it took for correlation, and the total amount of time before normal data processing could proceed. The fifth category, weapon employment and intercept, focused on the pilot's use of decision aids and the performance of the missile in the simulation. Some examples of tests in this area were pilot usage of the priority target and allocated weapon, accuracy of post-launch cues, missile launch results and missile intercept characteristics. The final category, pilot/vehicle interface, focused on the pilot's use of switches and displays.

6. CONCLUSIONS

The major conclusion of the test and evaluation was that the system provides improved situation awareness and decreased work load for the pilot, improving his combat effectiveness. Other conclusions resulting from the software development, integration, and flight simulation effort are as follows.

The Ada language was well adapted for this system. The use of Ada was successful after the compiler used became mature. Merely passing the Ada compiler validation tests does not guarantee an error-free compiler.

The distributed processing architecture, with modules coupled through a common data

- TRACKING CAPABILITY (P_t)
- IDENTIFICATION (P_{ID})
- WEAPON EMPLOYMENT CAPABILITY
- SYSTEM LETHALITY
- SURVIVABILITY
- INITIAL DETECTIONS/ TRACK RANGE
- TARGET ID RANGE
- WEAPON LAUNCH RANGE
- BLUE/RED KILLS
- BVR/WVR MISSION TRANSITION
- LOSS/EXCHANGE RATIOS
- KILLS PER SORTIE
- WEAPON TYPE LAUNCHES

Figure 12. Top Level MOPS & MOES

INTERNETTING	MULTI-SENSOR INTEGRATION

- INTERNETTED TRACK ACCURACY (POSITION & VELOCITY)
  - DURATION
  - UPDATES
  - FUNCTIONS OF TARGET DENSITY
- PASSIVE RANGING
  - TIME TO RANGE
  - GHOST TRACKS
  - ACCURACY
- DATA LINK
  - EFFECT OF DATA LINK RANGE
  - JOIN/REJOIN CHARACTERISTICS
	- MISCORRELATION
	- TIME BETWEEN TRACK UPDATES
	- TRACK DELETIONS
	- TRACK ACCURACY
	- TRACK COUNTS
	- SENSOR CONTRIBUTIONS
	- GATING ALGORITHM
	- EFFECTS OF LPI/PASSIVE
	- FILTER COVARIANCE (MSI & INF)

SENSOR MANAGER	**FIRE CONTROL**
- TIME IN FIELD OF REGARD PRIOR TO DETECTION - TIME DELAY FOR ID - USE OF RADAR FOR TRACK UPDATES - TRACK SERVICING - SEARCH DUTIES	- PRIORITIZATION ALGORITHM PERFORMANCE - MLE ALGORITHM PERFORMANCE - KILL ASSESSMENT - A-POLE & F-POLE - MISSILE SEEKER TURN ON

Figure 13. Algorithm Performance Evaluation

base and a high-speed data bus, was successful. With this architecture, it was important to have early definition and control of the data base and early attention to bus loading and protocols. With asynchronous operation of software modules, constant attention to the timing of data transfer was necessary.

The pilots considered the flight simulation to be adequate for valid evaluation of the system, in spite of the limited realism of the visual scene. This was because the scenarios, medium-range missiles, and beyond-visual range (BVR) target identification used resulted in BVR engagements.

The data rate used in the simulation for the wide-area data link, once every 10 seconds, did not give precise enough data to be fused mathematically with high-rate data. However, the wide-area data link targets could be displayed to the pilot on the same display as the other targets.

Specific results in regard to the six categories of testing that were discussed above were not available in time for this paper.

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The characterisation of targets is of primary interest because it is needed for establishing the tactical situation, optimising target acquisition and optimising armaments utilization. Due to the necessity of obtaining information on threats which have low signatures and are equipped with counter-measure systems the operational specification of airborne systems have come to rely on the technologies providing multispectral analysis of targets.

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